ENGINSOFT

futurities

Year 20
04
Winter
2023

SPOTLIGHT
Amazing Engineering

- Editor's Note

As the year draws to a close and the cold weather settles in in the northern hemisphere, we suggest you plan some uninterrupted time with your favourite hot beverage and settle down to read the **Spotlight** article of our winter issue, which is a long read that delves into the past, present and future of roller coaster design. Not only will you emerge from this treat culturally enriched with a deep understanding of how roller coasters have evolved since the 16th century, but you will also have an idea of how numerical simulation is applied for creating thrills and avoiding spills.

With the activities, meetings, and negotiations at the Cop28 meeting in Dubai well underway, our focus on sustainability continues in this issue in the article from BLOM Maritime, in our **Know-how** section, which looks at how digitalization can help decarbonize heavy industry, such as steel production that accounts for US$2.9 trillion of the global economy. Switching focus away from sustainability issues, we continue to delve into industrial case studies with an article from Ricardo that discusses how the company approaches motocycle component design to optimize stiffness, stress distribution and fatigue resistance while minimizing weight and ensuring the expected lifespan of the component is achieved. Our third article in this section investigates the use of Particleworks by Gamma Meccanica for the preliminary simulation study of a typical centrifuge currently produced by the latter company. It wanted to evaluate the behaviour of the centrifuge using moving particle simulation and discrete element method to gain a better understanding of the phenomena that are impossible to monitor experimentally as part of a feasibility analysis of different rotor configurations.

Our regular **Research and Innovation** section contains a couple more success stories from the EU's FF4EuroHPC project in which EnginSoft has been substantially involved. In the first of these, we examine the creation of a digital twin of airflow and inhaled drug delivery in a human airway, while the second success story examines the development of a specialized tool to simulate thermal sterilization processes in autoclaves used for food processing. Also in this section, we have an update to the SYNCH project. SYNCH stands for SYnaptically connected brain-silicon Neural Closed-loop Hybrid system and the project aims to create a hybrid system in which a neural network in the brain of a living animal interacts with a silicon neural network of spiking neurons via neuromorphic synapses with the intention of establishing a synapse-inspired reciprocal link between the networks and using the silicon neural network as a processing architecture to adaptively stimulate and rescue functionality in an animal model of disease.

Last but not least, the **Peeks** section of this issue contains a detailed article from TSNE that discusses a Coriolis mass calculation for a blow-torched shell resonator undertaken with Ansys. The article introduces a method to simulate glass forming with blow-torching and glass-blowing using Ansys Polyflow, and calculates the angular gain of a glass-shell resonator using Ansys modal analysis. Since over one million shell resonators are produced in this manner, this article should be of significant interest to those concerned.

Finally, allow me and all of the team to make you and yours our warmest wishes over the festive season. We look forward to working with you on innovation, research, and technology transfer again in 2024 and sincerely hope that the new year will usher in peace and prosperity for all.

Stefano Odorizzi
Editor in chief

"Allow me and all of the team to make you and yours our warmest wishes over the festive season. We look forward to working with you on innovation, research, and technology transfer again in 2024.

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EnginSoft S.p.A.
24126 BERGAMO c/o Parco Scientifico Tecnologico
Kilometro Rosso - Edificio A1, Via Stezzano 87 • Tel. +39 035 368711
50127 FIRENZE Via Panciatichi, 40 • Tel. +39 055 4376113
35129 PADOVA Via Giambellino, 7 • Tel. +39 049 7705311
72023 MESAGNE (BRINDISI) Via A. Murri, 2 - Z.I. • Tel. +39 0831 730194
38123 TRENTO fraz. Mattarello - Via della Stazione, 27 • Tel. +39 0461 915391
10133 TORINO Corso Marconi, 20 • Tel. +39 011 6525211

www.enginsoft.com
e-mail: info@enginsoft.com

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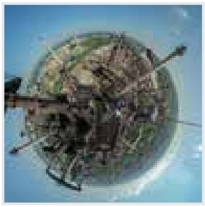

FACE TO FACE

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SPOTLIGHT

Amazing Engineering

Of desirous ups and downs… and upside downs

If you think of a theme or amusement park, the chances are that an image of a roller coaster leaps to mind. Roller coasters have evolved from the earliest prototypes in Russia in the 16th century to some of the highest, longest, and fastest vehicles for regular people to get an adrenaline rush today.

Amusement parks are expected to represent a market worth $89.2 billion by 2024, according to Statista. The United Arab Emirates is currently recognized as hosting the world's fastest roller coaster, known as Formula Rossa, which boasts a top speed of 240kph. The world's highest ride, which was the fastest before Formula Rossa, is the Kingda Ka in the Six Flags Great Adventure Park in the USA, which towers over its surroundings at 139m. Japan hosts the world's longest roller coaster of 2,479m. Known as the Steel Dragon 2000, you can find it in the Nagashima Spa Land park.

In this month's **Spotlight**, *Futurities* carries a fascinating article penned by EnginSoft's Livio Furlan on the origin, history, and evolution of roller coasters from their earliest prototypes in Russia in the 16th century on the banks of the Neva River of St. Petersburg, and then dives into detail on how numerical simulation of roller coasters works to ensure their success both as entertainment and from a safety perspective for users and operators. It's a fascinating read, just like these love-'em-or-hate-'em features that have symbolized amusement parks for almost as long as they have existed.

The roller coaster
A design challenge combining excitement and rigour

by Livio Furlan
EnginSoft

A roller coaster can be considered as a metaphor for life, with its ascents and descents characterizing life's ups and downs, evoking deep emotions from fears to be overcome to joys to share. It is probably for this reason that it is difficult to imagine an amusement park without immediately thinking of a roller coaster as the symbolic attraction, evocative of a desire to feel truly alive, to force oneself out of one's comfort zone, and to change the trajectories of one's daily routine, striving for experiences that fill one's days with life.

Historical background
What is the origin of the roller coaster, so emblematic of an amusement park?

Amusement parks date back to the medieval fairs scattered across Europe in the early Middle Ages. The word "fair" is derived from the Latin word "feria" used to describe the religious festivities that were celebrated during the Roman Empire. Similarly, in the early Middle Ages, villages organized fairs in the grounds adjacent to the local church or abbey for the feast of their patron saint.

Edward I of England, however, banned what he considered to be a desecration of the churchyard, forcing fairs to be held in other public areas such as town squares. Thus fairs evolved from being festivals to celebrate patron saints to becoming popular attractions and meeting places for local communities. Over time, they also became recreational, commercial and tourist attractions, evolving into today's amusement parks.

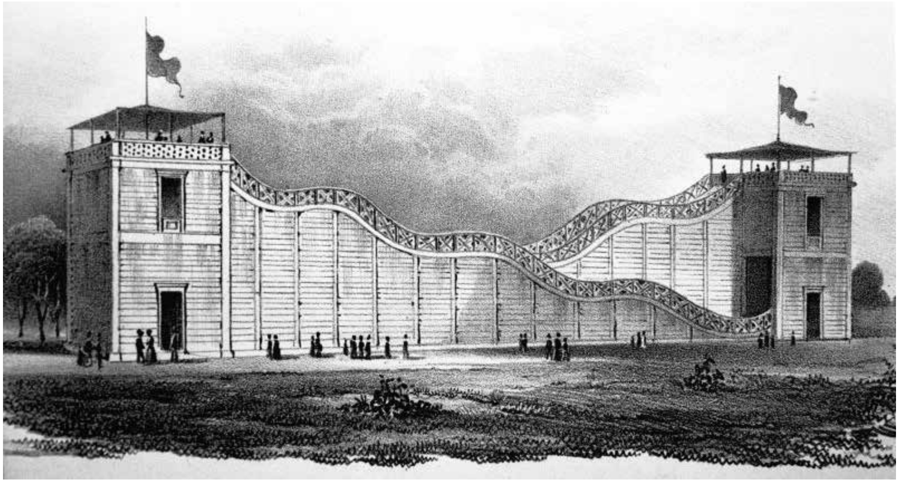
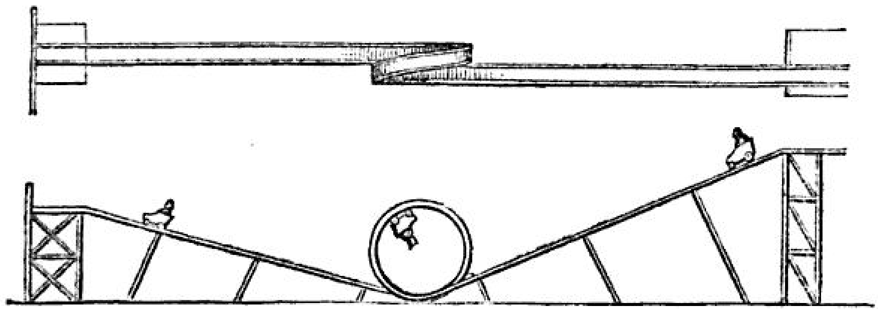
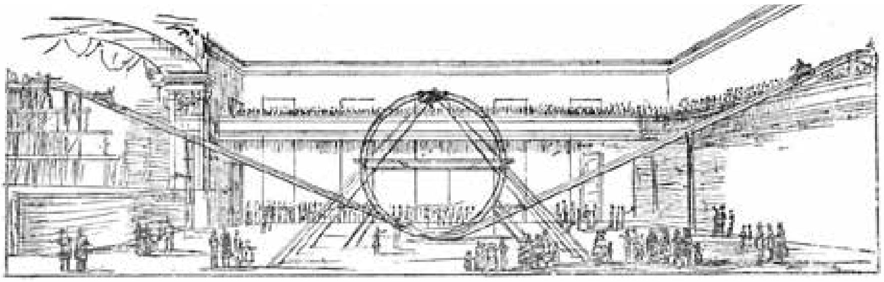


Fig. 1. The first roller coaster in Tivoli Gardens in Copenhagen, Denmark. Public domain, via Wikimedia Commons.



Simple design diagram of a centrifugal railway from the 1840s. Hutchinson, Higgins, et al. Public domain, via Wikimedia Commons.



A detailed sketch of a Centrifugal Railway in Manchester. Illustration unknown, published in work by Powys-land Club. Public domain, via Wikimedia Commons.

Fig. 2. Centrifugal railway.

As fairs spread across Europe as far as Siberia and eastern Russia (despite the harsh climatic and environmental conditions), they became important commercial gatherings. From the 16th century onwards, Russian cities near rivers – in particular, St. Petersburg with its Neva River – built numerous "ice slides" or "flying mountains" that became pseudo-permanent attractions thanks to the cold temperatures.

The "Russian Mountains" purposely built around St. Petersburg in the 17th century as part of its winter festivals, featured 20-25-metre-high wooden structures with wooden stairs that led up to the 180-metre-long ice slides with slopes steeper than 100% (the angle of the slide was about 50 degrees relative to the horizontal). Users would ride down the ice-covered wooden slides on sledges made of hollow blocks of ice filled with straw at first and later made of wicker. The slides were sprayed with water daily to keep the ice slippery while sand was sprinkled along the bottom of the slide to slow the descent, allowing the users to climb the ladder up to the next slide to continue the fun of "flying down".

Tsarina Catherine II, a great fan of the thrills provided by the slides, commissioned a pair to entertain herself and her courtiers at her palace in Oranienbaum on the Gulf of Finland, and had wheels added to the carts and grooved rails added to the slides to create a summer version of the "flying mountains".

But who created the first "real" roller coaster using carriages with wheels? Some historians credit the Russians with building the first machine on wheels but during Napoleon's invasion of Russia in 1812, the French discovered this form of entertainment, brought the idea back home, and significantly developed it. They built two roller coasters in Paris in 1812, known respectively as "Les Montagues Russes" at Belleville with tracks and carts on wheels with axles, and "Promenades Aeriennes" or the Aerial Walk which had two opposing curved tracks that met at the base of the attraction where a climbing system brought the carts back to the top for the next ride to take place.

In the wake of the Napoleonic wars and the wave of nationalism spreading across Europe, the French began to organize national exhibitions, culminating in the French Industrial Exposition of 1844 in Paris. This fair was followed by other national exhibitions in the Old Continent, participation in which was facilitated (and enabled) by the technological advances at the height of the Industrial Revolution that led to the construction of navigable waterways, railways and steamships. Exhibitions resemble medieval fairs in their ability to attract people from faraway places and, like medieval fairs, these increasingly international exhibitions attracted trade and soon began to showcase and promote the technical-scientific achievements of nations.

In was here that the entertainment attractions provided for the participants of the exhibitions also witnessed innovation which today would be defined as Research and Development. Hence, the first example of a centrifugal railway (Fig. 2) i.e. a looping roller coaster, came into being. This attraction was installed in 1845 at Frascati Gardens in Le Havre and consisted of a track descending from a height of 43 feet (13m), a loop of 13 feet (4m) in diameter, and an ascending section to enable the rider's cart to stop. The attraction operated for 20 seasons but went out of fashion and was closed following an accident that claimed one life.

Although there were many labour injustices during the Industrial Revolution, industrialization generally freed millions of people from subsistence farming and created more leisure time for the average population. In particular, many Americans began working fewer hours and had more disposable income.

As a result, the roller coaster, progeny of the Russian Mountains, was no longer a monopoly of the ruling classes and began to be built everywhere. America, specifically, had an abundance of land to build large rides, the engineering know-how to create ever more innovative roller coasters to meet the demand of a growing population of thrill-seekers, and the forests to provide the construction material: wood, which was used to manufacture roller coasters from the second half of the 19th century until the first half of the 20th century.

LaMarcus Thompson, often considered the "Father of the Roller Coasters" and the "Father of the Gravity Rides", emerged in the States of the Union of that time. He is credited with the conception and construction of "Coney's Switchback Railway" in Coney Island in New York in 1884. This structure features a tower from which passengers board a large cart with bench seats. Like a roller coaster, the trolley descends a 600-foot-long (183m) ramp to another tower, travelling at approximately 10kph. At the top of the second tower, the cart is moved onto a second track to allow it to return to the first tower.

Roller coasters in the short century

In the wake of Coney's Switchback Railway's popularity, others "designed" and built bigger and faster rides. Shortly afterwards, Charles Alcoke developed the first attraction with a complete oval circuit, also made of wood, called the Serpentine Railway. Although steel was already widely used in the construction industry, especially in the railway sector, its debut in roller coaster production only dates back to 1959, when the Disneyland theme park introduced a new twist in roller coaster design with the Matterhorn Bobsled. This was the first roller coaster with a track made of tubular steel parts.

Unlike traditional wooden tracks, tubular steel tracks can be curved in any direction, allowing designers to incorporate inversions into their designs. This is why many modern roller coasters are made of steel, although a few wooden ones are still being built to satisfy the fans of this type of coaster.

The years from 1970 to 1990 saw the construction of the largest number of roller coasters since the 1920s. Anton Schwarzkopf (a German roller coaster designer) and F.lli Pinfari (an Italian roller coaster manufacturer) pioneered the use of tubular steel tracks. They ushered in a new era of roller coasters, adopting the Loop feature and introducing the first attempts at new and even more exciting shapes such as the Corkscrew, the Immelmann Turn, the Dive Loop, the Cobra Roll, etc. It was on the basis of these shapes that a new revolution in the design and construction of roller coasters took place between the 1990s and 2000s in order to increase excitement levels:

- **1992**: the first Inverted Coaster was introduced; this is a roller coaster in which the train runs suspended from the tracks and the seats are connected directly to the wheel bogies;
- **1996**: the first Coaster to use the LIM (Linear Induction Motor) propulsion system which "shoots" the cars to the top of the first climb without the need for traditional lifting systems which are made with chain and sprockets (chain lift) or with special wheels equipped with tyres (boosters);
- **1997**: the first Flying Coaster. This type of rollercoaster is designed to simulate the sensations of flight and keeps passengers in a prone position for the duration of the ride. Like Inverted Coasters, the carriages are suspended below the track with passengers' bodies positioned parallel to the track itself;
- **1998**: the first Dive Coaster. This type of steel roller coaster gives passengers a moment of free fall with a drop of at least 90 degrees (Oblivion, Alton Towers);
- **1999**: the first Floorless Coaster. In this version of a steel roller coaster, passengers sit inside a floorless car and their feet swing just above the track.

Safety matches emotion

As may be expected, partly due to the construction possibilities afforded by the evolution in production technologies, the use of steel as the main manufacturing material, and increased understanding in context of phenomena that formerly lacked clear explanation (fatigue behaviour, for example), the limits of ride performance research have been – and are still being – pushed forward every day. The ensuing challenges, safety first and foremost, are therefore significant and decisive and leave no margin for error in evaluating

the mechanical-structural behaviour of these complex systems in response to stressful dynamic actions. Therefore, the only way to fully "understand" this type of structure and to design the structural components and mechanical parts of the entire carousel properly and safely is to use virtual prototyping with associated numerical simulations.

Given the complexity of a roller coaster project, especially one with above-average performance, numerical simulations must obviously be combined with the requisite technical skills in order to provide enthusiasts with increasingly exciting products, as well as to integrate the various stages of design of the track and the vehicle/train that travels it, with an eye to comfort and the requirements/limits of acceleration imposed by sector standards.

A numerical approach to roller coasters design

Accordingly, the different aspects of roller coaster design clearly require specific, integrated, and interconnected development phases. Beginning with the customer's requirements, these phases move from feasibility to execution and use virtual prototyping tools (CAD-CAE-FEM) that not only guarantee the precision and safety of the final product, but also offer unbeatable advantages in terms of cost control.

The added value of virtual prototyping is also evident in the quantity and quality of information obtained, which influences the designer's ability to overcome engineering challenges without sacrificing competitiveness and business objectives.

Furthermore, the customization of calculation and verification tools (calculation procedures) in a virtual testing environment accelerates the conception and design phases, reduces errors, and enables the acquisition of skills that can be used in subsequent processes/projects.

It is safe to say that comprehensive and advanced simulation tools, complemented by specific knowledge, are key to investigating the mechanical-structural phenomena typical of roller coasters and achieving ever higher design standards and reliability levels.

The specific, integrated, and interconnected development phases outlined above are summarized below.

Step/Phase 1 – Client requests

In this first phase, the following aspects are considered depending on the type of roller coaster being designed/built:

- Customer ideas and/or requirements;
- Track ideas (children, families, thrill factor…);
- Vehicle/car ideas (standard, spinning, inverted, etc.);
- Boundary and constraint conditions by location: flat terrain, hillside, open area, shopping centre, etc.

Step/Phase 2 – Initial proposals (architectural evaluation)

Considering the customer's requests and, therefore, the type and level of thrill desired for the attraction, initial drawings are developed to share ideas leading to the final design. The activities therefore involve:

- Issuing multiple layouts based on the customer's idea;
- Producing 2D drawings (plans, elevations) for an initial assessment-evaluation;
- Generating the first renderings with simplified 3D of the roller coaster in the right environment (including video);
- Defining the preliminary ride performance data (based on experience).

Step/Phase 3 – Layout based on dynamic response

Once the preliminary track layout has been defined, the first dynamic calculations necessary to identify where to insert the appropriate transition curves and to define the track elevation values to make the curve transitions more comfortable are developed:

- Modifying the 2D drawings (plan and elevation) with the introduction of transition curves;
- Generating the 3D spline (centreline) and introducing spatial figures (Loop, Immelmann, Corkscrew);
- Preliminary ride dynamics (point masses);
- First track banking evaluation and preliminary safety checks.

Step/Phase 4 – Interactive optimization process

This is the main optimization process and is based on recursive steps, with a full multibody analysis performed as a final check on accelerations once the track geometry has been locked:

- 2D/3D layout modification;
- Simplified dynamics (point masses);
- Tracking of banking evaluations;
- Verification of environmental constraints (safety envelope);
- Full multibody analysis;
- Acceleration assessment and data verification, for example, with respect to the requirements of EN 13814 (see Fig. 4).

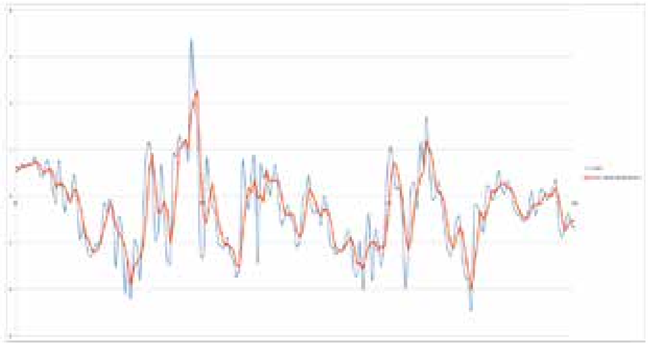


Fig. 3. Example of a comparison between real acceleration and calculated acceleration.

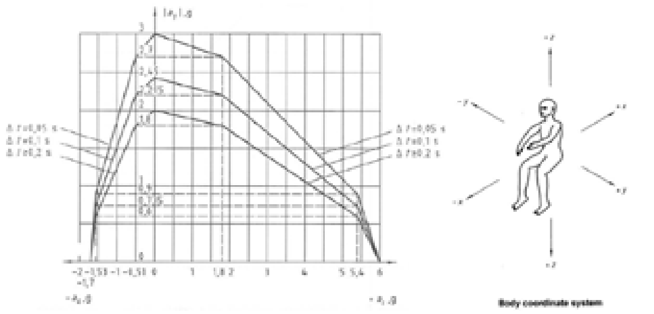


Fig. 4. Domain within which the accelerations a_y and a_z must lie (from the requirements of EN 13814).

Comparing the results (accelerations) of virtual prototyping (multibody models) with accelerometric data obtained from tests over the years on their corresponding real-world tracks provides the certainty that numerical simulations, when conducted with the appropriate experience and expertise concerning physical phenomena, are reliable and provide consistent data upon which to develop the roller coaster design.

This means that the project becomes more robust and secure as it develops on the basis of validated mathematical models. After all, innovation, a field that rightly includes roller coasters, requires flexibility; flexibility requires abstraction (as in concepts and theory); and the language of abstraction is mathematics. However, mathematics is more than language: it can be used to deepen knowledge, to search for optimal solutions, and to design efficient algorithms based on the mathematical equations (algebraic, functional, differential, and integral) that support the physics of systems.

Together, technological innovation and mathematics can form a virtuous interaction process to generate a reliable representation of the mechanical-structural behaviour of roller coasters and their components.

Step/Phase 5a – 2D/3D model of the roller coaster attraction

After dynamic optimization, the roller coaster structures, and car frames/components can be modelled in detail to prepare the final drawings/documentation for construction and delivery:

- Generating the 3D primary model of the full ride containing columns, rails, base frame, station, etc.;
- Issuing the 2D workshop drawings with all details (materials, welding procedures, NDT tests, etc.);
- Drawings for tube bending and track construction (3D coordinates and jigs);
- Manuals (operational, inspection), and risk assessment documents.

Step/Phase 5b – Roller coaster structural models

Based on the 3D master models and the dynamic multibody model, the following activities are conducted for the final calculation phase of the overall attraction.

- Postprocessing of accelerations related to the vehicle system which are provided both by automatic calculation (based on the physical-mathematical relationships in industry standards) and by dynamic multibody model, also for comparative purposes;
- Evaluating the forces on the carriage wheels (load-bearing wheels, guide wheels, side wheels) for each load case associated with the curvilinear co-ordinate of the train's progress along the track;

Fig. 5. Finite element model of a roller coaster.

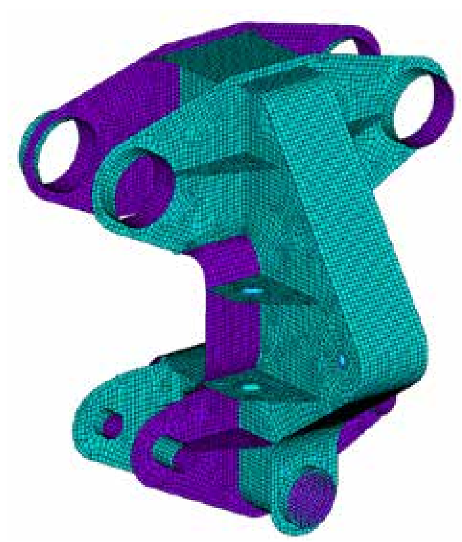


Fig. 6. Finite element model of a car bogie.

- Creating a 3D beam+shell finite element model with properties and group assignments to comply with the automatic strength and fatigue check procedure;
- Exporting a TXT file containing all data concerning the roller coaster structure to perform the FEM analysis (see Fig. 5);
- Performing linear/non-linear structural analyses considering both the environmental actions (if any) and the forces transferred from the carriage to the track;
- Performing code verifications in terms of strength and fatigue testing of the structural elements, welded connections/joints, and bolted connections/joints.

Step/Phase 6a – 2D/3D carriage model

Depending on the type of car/train (standard, spinning, inverted, etc.) the design of the structural and mechanical parts and their theme is developed. These activities include:

- Transforming ideas into first sketches (mechanical, structural, and theming solutions);
- Transforming preliminary 2D drawings into 3D models (including the fibreglass bodies forming the scenic part of the train);
- Creating the detail design of the car bogies, axles, and frames;
- Defining the mechanical connections between the structural parts, and designing the electrical plan, and all ancillary parts of the cars/train.

Step/Phase 6b – Mechanical-structural calculations/models of the carriage

Once car design is complete, the numerical models and verification calculations (mainly fatigue calculations) of the various components are developed:

- Creating a 3D beam+shell finite element model of the bogies (see Fig. 6) and the car frame;
- Performing linear/non-linear structural analyses considering the accelerations experienced by the cars/train during a full lap of the ride;
- Conducting normative checks regarding the strength and fatigue testing of the bogies (see Fig. 8), structural elements, pivots, axles, connecting bars, welded connections/joints, and bolted connections/joints;
- Performing optimization activities involving/reducing the mass of the carriages/main components of the train (reducing the train's masses reduces the forces acting on the carriages and consequently on the track).

The final point above is a key activity, and involves phases 5b, 6a and 6b. These optimizations (which actually reduce the masses themselves) can be achieving by working on two levels: firstly by containing/decreasing the weights by modifying the component geometries, and secondly by introducing lighter materials than steel (such as austempered cast irons, or aluminium alloys).
The second level, due to its use of "modellable" materials, enables substantial redesign of the parts and components of the cars and results in the creation of a "lightning train", i.e. the convoy's reduced mass allows it to traverse the track in a more restrained manner requiring less energy to be launched and slowed along the route and reaching higher speeds (or greater heights) than an equivalent "traditional train" with the same amount of energy applied at launch.

The regulatory framework

This integrated numerical approach incorporates the regulatory requirements both for the calculation of the dynamic actions affecting the track and the cars/train, and for the development of the verifications to calculate the minimum safety margins necessary to achieve compliance. Some of the standards are listed below:

- ASTM F2291-23: Standard Practice for Amusement Ride Design;
- EN 13814: Fairground and Amusement Park Machinery and Structures;
- EN 1993-1-9: Design of Steel Structures – Fatigue;
- IIW - Recommendations for Fatigue Design of Welded Joints and Components (for Hot Spot Stress approach);
- UNI 7670: Mechanisms for lifting devices – Instructions for the calculation (considered for the calculations/verifications of non-welded components).

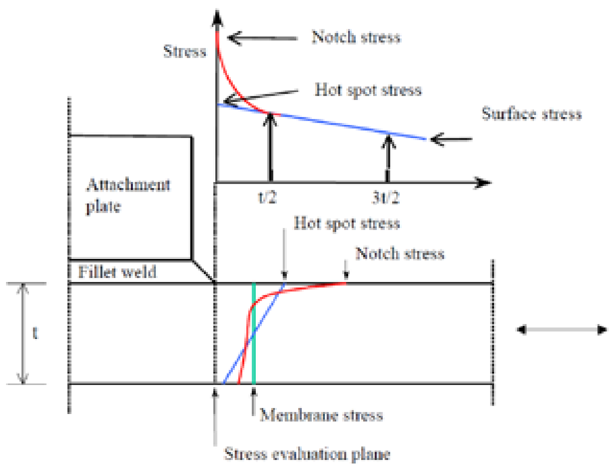


Fig. 7. Schematic stress distribution at a hot spot (taken from the Recommended Practice DNV RP-C-203).

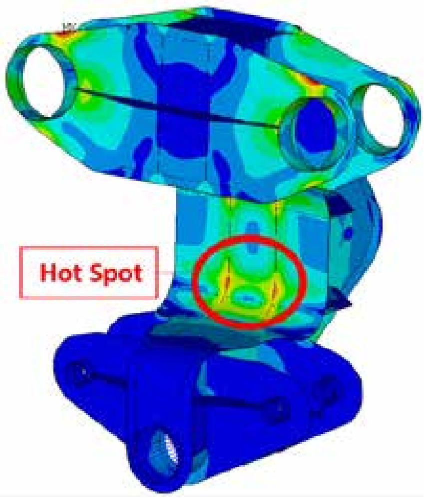


Fig. 8. Bogie region to be verified by hot spot method.

Regulatory verifications are conducted for strength resistance and buckling resistance as well as fatigue response (fatigue resistance) checks. As previously mentioned, for roller coasters (and all rides in general) the phenomenon of fatigue on metallic materials, associated with the cyclic nature of actions and stresses, is decisive and sizable.

Therefore, an extensive check is necessary for each area and, particularly, for regions with stress concentrations that may trigger problems resulting in possible failure.

Fatigue damage calculations use appropriate calculation methods (e.g. the rainflow counting algorithm) at each significant point based on the stress history (derived from each lap) and define the number of cycles in a specific stress range ($\Delta\sigma_i$) as well as the value of accumulated damage, using appropriate S/N curves and the Palmgren-Miner rule.

Detailed FEM analyses of the complex welded construction parts, whether in roller coaster structures, bogies and/or car frames, may be necessary to reliably determine stress concentrations. However, even with the aid of finite-element analyses, it can be difficult to assess which "nominal stress" should be used for the S/N curves, since part of the local stress from a specific detail type is already taken into account in the S/N curve for that very type of detail.

Sometimes, it may prove more convenient to use an alternative approach (the so-called hot spot method) to calculate fatigue damage when local stresses are obtained from the finite element analyses and when notch stresses are difficult to assess due to the significant dispersion in the local weld geometry and different types of imperfections. The numerical procedure for the hot spot method is based on two assumptions:

- the notch stress factor that results from the welding is included in the S/N curve to be used (as specifically defined by the standards concerning the calculation of fatigue damage); this S/N curve can usually be considered as the hot spot S/N curve;
- stress concentration caused by the geometric effect of the actual detail is calculated by using a shell or solid finite element model with a suitably fine mesh to obtain a reliable value for the SCF (stress concentration factor) which increases the nominal stress.

Since the notch effect of the weld is included in the S/N curve, the stress at the hot spot is derived by extrapolating the structural stress at the base of the weld as exemplified in Fig. 7. Note that the strain used as the basis for this extrapolation must be external to that affected by the weld notch but close enough to detect the effects of local geometry.

Drag reduction – CFD's contribution

Enthusiasts' search for greater thrills has driven designers and manufacturers to creating roller coasters with progressively longer tracks, more figures/inversions along the tracks, and taller structures for the trains

of cars to scale. LIM propulsion systems allow trains to be propelled at higher initial speeds, due to the greater efficiency of the launch systems.

The speeds and thrill factor are augmented by increasing the cross-sectional dimensions (more passengers per row) and the number of cars and, therefore, the load capacity, i.e. the number of passengers per run. As the transversal and longitudinal dimensions of trainsets grow, evaluating aerodynamic actions, i.e. the interactions between the air and the solid body of the train as it moves forward, becomes important. In fact, during the lap, the initial kinetic energy (of launch by LIM or, in traditional lifting systems, generated by the first descent) is gradually lost due to friction and air resistance.

It is precisely the latter that can influence the speed of the train/carriage and, therefore, the length of the ride. If one underestimates the kinetic (or potential) energy that the train must have at the start of a turn, the train risks coming to a standstill on a gradient before it can descend and continue along the track. It therefore follows that it becomes important to foresee the dissipation of kinetic energy caused by drag in certain situations.

Since wind velocity increases with altitude, wind forces opposing the train's motion can be particularly significant on taller roller coasters, also relative to their interaction with the speed of the train. Aerodynamic studies therefore play an essential role in the design simulation of modern, extreme roller coasters in order to cater for the high speeds and the forces opposing the train's progress along the track.

Furthermore, drag can increase substantially on the winding parts of high-speed routes when the carriages (2-4 seats) of the same train fan out, widening the frontal area of the entire train that is exposed to the wind. Computational fluid dynamics (CFD) can play an essential role in the design of modern roller coasters to accommodate high-speed resistance (and wind-induced actions).

To obtain indications of the effect of passengers on the drag coefficients, numerical analyses use models of the train with (occupied seats) and without (empty seats) passengers. The geometry of the entire train is generated by copying the surface geometry of a single car/carriage (with and without passengers), as many times as the number of cars in the train.

The train's overall geometry is placed in a sufficiently large air domain to ensure that the sensitive results are not affected by edge effects. Numerical steady-state simulations are performed on the domain, which is divided into polyhedral cells, using the k-ε turbulence model for different apparent wind speeds and directions. The aerodynamic coefficients (drag coefficient in particular) are calculated from the CFD analysis results, which are used to define the drag resistances.

The benefit of CFD simulation lies in the possibility of redesigning seat and fibreglass shapes as deemed appropriate to significantly improve performance, without having to conduct real experiments. In other words, CFD simulations enable an in-depth understanding of the aerodynamic behaviour of the trains, giving designers new inspiration to develop progressively more exciting roller coasters.

For more information:
Livio Furlan - EnginSoft
l.furlan@enginsoft.com

A design study of a centrifuge for separating water and plastic

by Lorenzo Iorio
Gamma Meccanica, Plastic Division

Introduction and motivations

This paper presents the preliminary simulation study of a typical centrifuge currently produced by Gamma Meccanica. The objective of this study is to evaluate the behaviour of the centrifuge using moving particle simulation and discrete element method (MPS-DEM) simulation techniques with Particleworks 7.2.1 to gain a better understanding of phenomena that are impossible to monitor experimentally.

Qualitative and quantitative results, such as the distribution of water and plastic particles within the centrifuge, will be compared to identify key factors for further analysis and improvement in future studies. Particular phenomena like blade erosion due to particle impact will be used for qualitative validation of the model.

The presented model and results formed part of a feasibility analysis of different rotor configurations. The varying distribution of the water and particles enabled observations about the performance of different rotor geometries in terms of energy efficiency and moisture in the final product. The results of the numerical comparison will be very useful for future improvements not presented in this article.

Centrifuge design

The centrifuge design presented in this study consists of a number of different geometries as listed here and visible in Fig. 1:

- Rotor 1: closed square section surrounded by four blades.
- Rotor 2: closed circular section surrounded by four blades.
- Rotor 3: open square section surrounded by four blades.

The importance of simulation

Using MPS-DEM simulation to analyse the centrifuges used in plastic recycling plants makes it possible to investigate phenomena that are impossible to monitor and understand experimentally.

Prior to the introduction of simulation, each machine was designed using the considerable experience of Gamma Meccanica's engineers and technicians and with valuable customer feedback that is always important for continuous improvement. Simulation will now enable the pluriannual experience to be represented

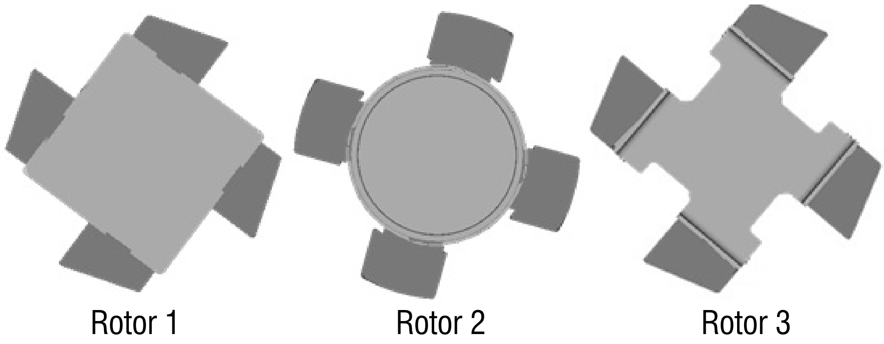


Fig.1. Comparison of different rotor sections: a) closed square section, b) closed circular section, open square section.

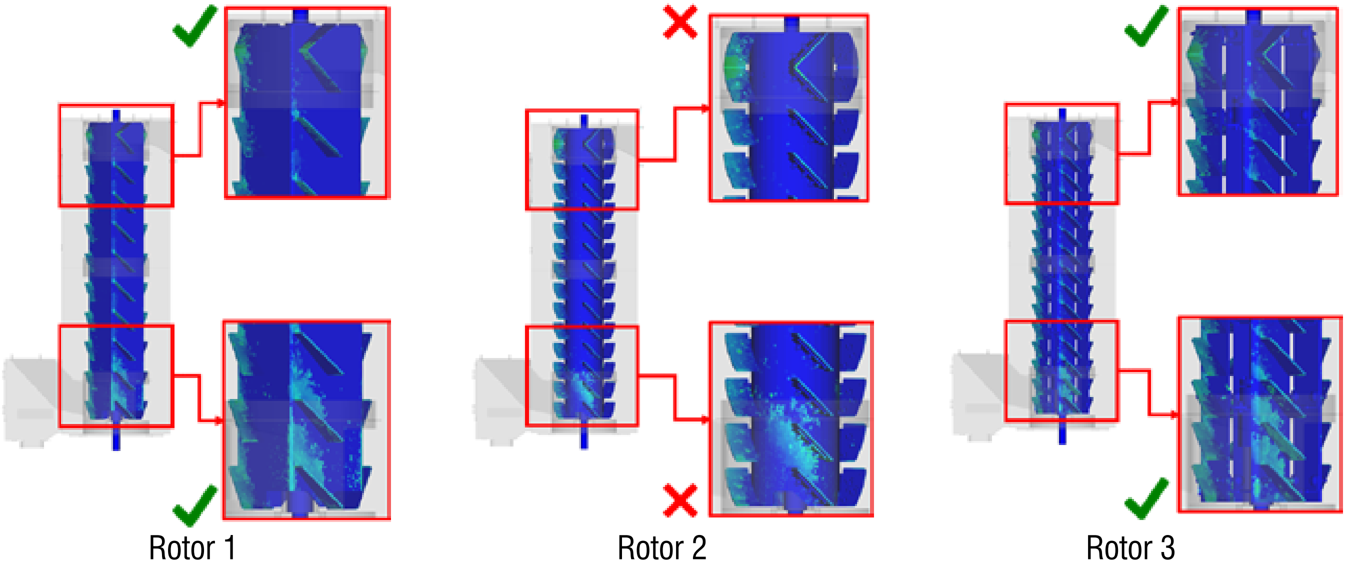


Fig. 2. Mapping the water distribution on the rotor surface: a) closed square section, b) closed circular section, c) open square section.

numerically and to improve current solutions with new and innovative configurations not previously studied due to the high experimental time costs.

Simulation results

The simulation study conducted by Gamma Meccanica provided valuable information on the centrifuge design's behaviour and performance. The results revealed the distribution of the water and plastic within the system and exposed areas for improvement. In the following paragraphs, we discuss the detailed engineering analysis and observations emerging from the simulation. One of the main purposes of the simulation was to assess the distribution of water and plastic particles within the centrifuge. Mapping the flow patterns (Fig. 2) demonstrated the influence of different rotor sections on the distribution.

The simulation showed that the rotor with the rounded cross-section (Rotor 2) let a considerable amount of water flow upwards to the top of the system. In contrast, the square cross-section of the rotor restricted the flow of water, resulting in a more concentrated distribution of water towards the lower part of the system. This analysis provided a qualitative understanding of water distribution and its relationship to the rotor design. The observed differences in water behaviour between rotor sections formed the basis for further investigation into their impact on overall performance.

Another critical aspect of the simulation was to evaluate the impact of plastic particles on the centrifuge. The simulation provided detailed information on the behaviour of particles and their effect on the machine's long-term performance.

The results indicated that some sections of the rotor were impacted significantly by the particles, suggesting potential erosion in those areas over time (Fig. 3). These findings were supported by qualitative observations from customers, who experienced similar defects due to particle impact.

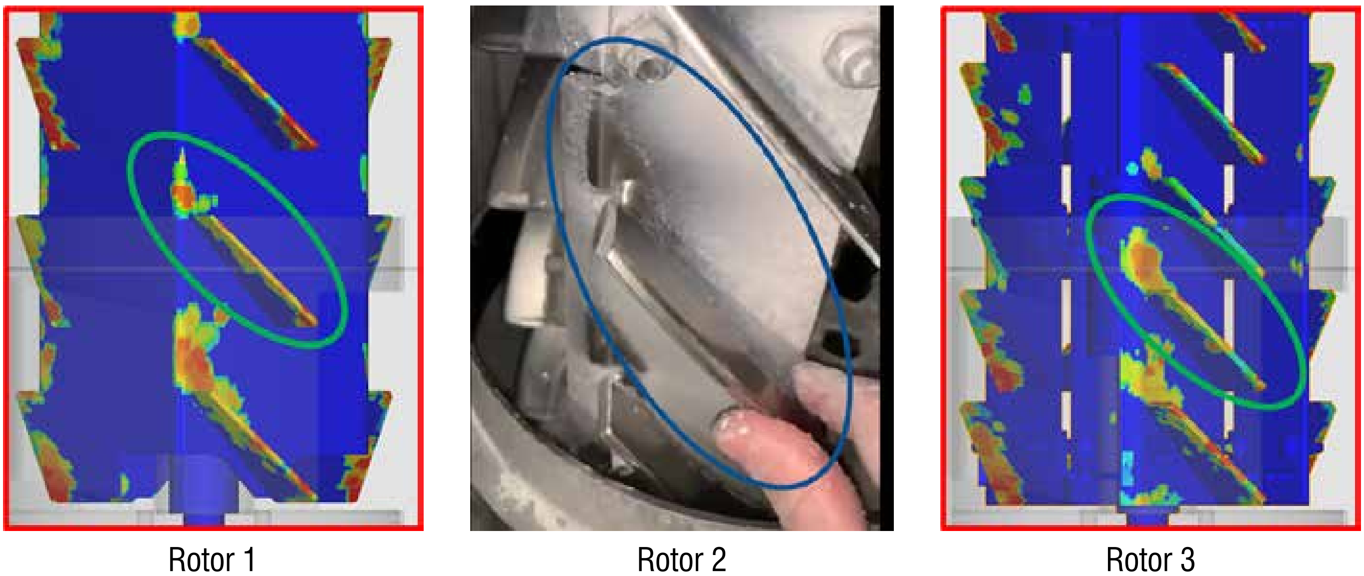


Fig. 3. Erosion phenomena – numerical-experimental comparison: a) numerical evidence on rotor with closed square section, b) experimental evidence on rotor with open square section, c) numerical evidence on rotor with open square section.

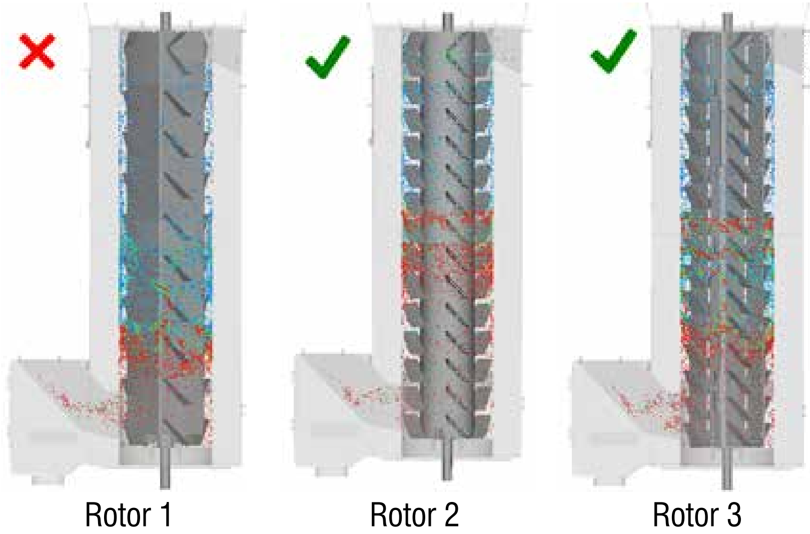


Fig. 4. Plastic particle distribution inside the rotors: a) closed square section, b) closed circular section, c) open square section.

The analysis of particle distribution (Fig. 4) using numerical density visualization showed that the first rotor was not efficient at expelling plastic particles from the system. This suggested that although the first rotor was efficient at expelling water, it struggled with plastic separation. Furthermore, the analysis of energy consumption (Fig. 5) revealed that the second rotor required more power than the other two rotors. Based on the results of the water distribution, a qualitative analysis of the amount of water expelled by the rotors at the plastic particle outlet allowed the humidity of the final product, which should be as low as possible, to be assessed. The results presented in the figure below show that Rotors 1 and 3 dramatically reduce the moisture content of the end product compared to Rotor 2.

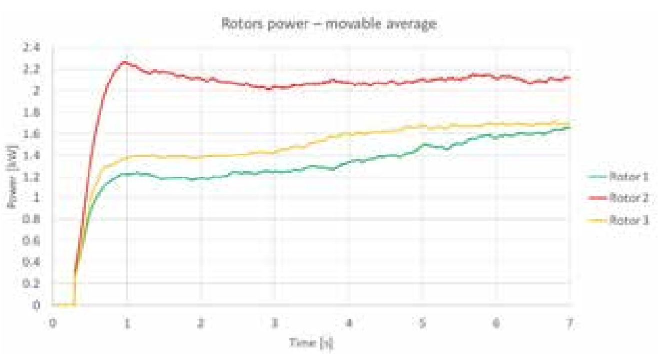


Fig. 5. Rotor energy consumption.

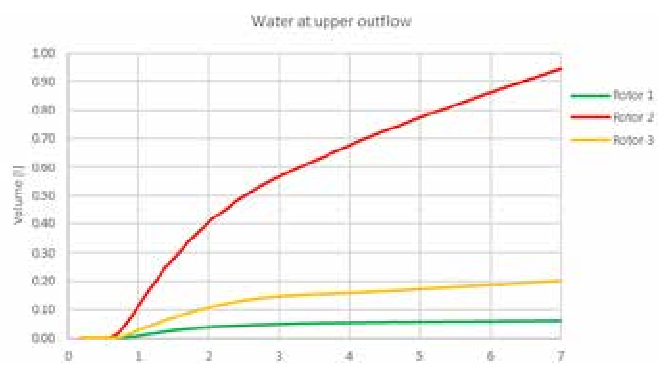


Fig.6. Water volume expelled by the rotors at the plastic outlet in 7s.

Conclusions and future developments

The proposed study allowed the behaviour and performance of different rotor models to be better understood in terms of water and plastic particle distribution, blade erosion, energy consumption, and moisture levels in the final product.

The results showed that Rotor 2 with the round cross-section performed worst for energy consumption and product humidity. Rotor 1 performed well in energy consumption and humidity but worst for plastic particle distribution along the rotor's axis. Rotor 3 demonstrated a good compromise between energy consumption, water and particle distribution, and final product humidity (quality).

All results are sufficiently in line with technical experience and customer feedback gathered over the years, so as a result this model will be used for future improvements. Rotor 3's configuration will also be used as the base configuration for new design proposals.

For more information:
Michele Merelli – EnginSoft
m.merelli@enginsoft.com

About Gamma Meccanica

Gamma Meccanica is a world leader in mineral wool production lines, both single machines and complete lines for the production of mineral wool, i.e. stone wool and glass wool.
The company also manufactures special lines for the production of pipe sections and sewn mattresses, laminate production lines, ceramic fibre machinery and hydroponic lines for stone wool and glass wool. Gamma Meccanica's machinery offers a combination of high performance and advanced technology. It meets and exceeds customer demands by constantly improving quality and energy efficiency through technological advancement and high levels of technical support, while meeting the strictest environmental standards. Established in 1977, today the company has three divisions, each focused on a specific sector:

- the insulation division designs and produces lines for the production of mineral wool;
- the extruded polystyrene division creates systems for the production of XPS boards;
- the plastic division specializes in lines for recycling plastic material.

Its constant technological and applied research and highly qualified staff makes Gamma Meccanica one of the main players in its field globally. Gamma Meccanica designs and manufactures its systems at its plant in Bibbiano in Reggio Emilia in Italy which allows the company to directly control both development and the full production process.

face to face with Pietro Del Negro

Senior CAE engineer at Ricardo

How Ricardo predicts the life of motorcycle components

by Pietro Del Negro
Ricardo

Pietro Del Negro is a senior CAE engineer at Ricardo's Rimini Technical Centre in Italy, specialising in motorcycle and light mobility applications, including simulation, analysis, and systems integration for global OEMs and tier-one suppliers. In this article, Del Negro explains how Ricardo is developing solutions to support its customers to predict the lifecycle of motorcycle components, using finite element analysis (FEA) and fatigue analysis.

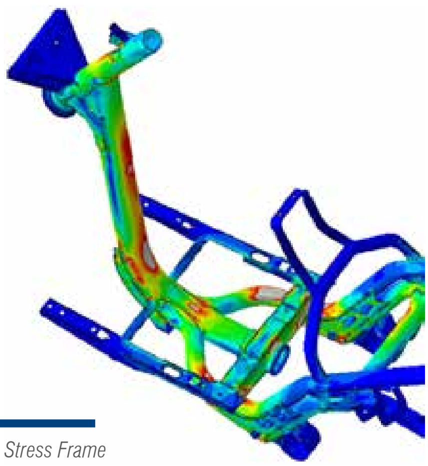
How important is load cases evaluation?

Ricardo has developed a methodology to calculate analytically dedicated load cases for a range of motorcycle and light mobility applications. The target is to optimise stiffness, stress distribution and fatigue resistance, minimising the weight, and allowing for an expected target, or infinite life, for each motorcycle component.

These calculations enable our customers to accurately determine how different components will perform in any given situation by representing, via FEA, all the critical events that a vehicle may encounter during its life cycle. FE model calibration through comparison of results and road test data from strain gauges allows numerical models and hypothesised load cases to be validated, reducing the gap between the virtual and the real worlds. This instils confidence in all stages of design and results in shorter product time to market.

How do FEA and fatigue analysis work?

FEA and Fatigue Analysis is used to understand structural behaviour during the design phase of a project to determine safety and identify where improvements can be made. There are several types of analysis, including static linear and non-linear, dynamic, topology and fatigue analysis. Each plays a key role in the development of a motorcycle or light mobility vehicle. Tools such as Nastran, Abaqus,



Stress Frame

OptiStruct, HyperWorks, Femap and FEMFAT are all used by Ricardo to support analysis processes. Each analysis plays an important role in motorcycle development. For example, stiffness analysis has an impact on several aspects of a motorcycle, including:

- Drivability – stiffness determines the vehicle's response to all dynamic events (curves, bumps, potholes, etc.)
- Comfort – the stiffness is directly linked with vibration in the vehicle's frame.
- Safety – the stiffness has a big impact on safety because it influences the capability of the frame to absorb the energy in the case of a dynamic event.
- Sensitivity – the stiffness influences the sensitivities of the rider to recognise the dynamic behaviour of the vehicle and anticipated reaction to dynamic events. This enables the rider to better preserve safe conditions. Frames that are too stiff can be dangerous as they are less likely to alert the rider to a dynamic event, or a sudden change of wheel grip.

The optimal stiffness value guarantees and respect all the above conditions.

Correct evaluation of vehicle rigidity is fundamental. Evaluated stiffness can often be error prone, e.g. torsional stiffness can be affected by lateral stiffness and vice versa. Ricardo has developed a method to properly calculate pure stiffness values (i.e. bending, torsion).

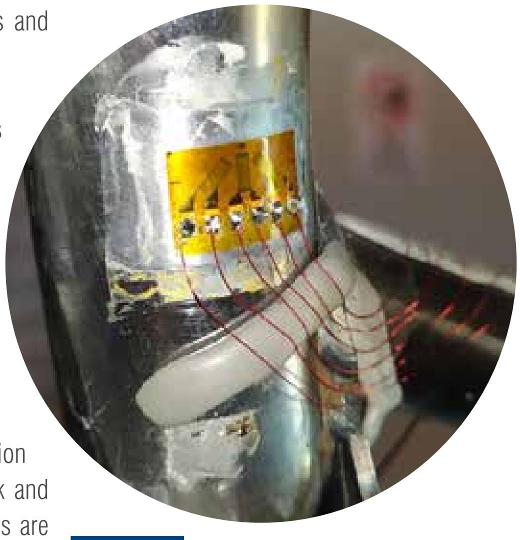
In most cases, the rigidity calculation involves the main frame, the front fork and the swingarm, however, stiffness values are also important to obtain a suitable overall correlation to ensure the correct behaviour of the whole vehicle.

Ricardo continues to compare and analyse different brands of motorbike and light mobility vehicle to ensure adequate benchmarks.

What is fatigue analysis?

Fatigue analysis makes it possible to assess the deterioration of structures subject to cyclic loads. Sometimes, it is difficult to predict and avoid problems and improve critical areas.

Often a fatigue phenomenon begins with nucleation and increases continually before leading to a definitive failure of the component. This is largely due to the progressive reduction of its cross section.
Ricardo uses a holistic approach in developing a motorcycle or light mobility vehicle, starting with concept and styling, and progressing on to the evaluation of



Strain Gauge Application

specific load cases, component engineering, FEA and Fatigue analyses. Providing good results are obtained, the road tests follow, until the start of production.

Fatigue analysis is integral to the normal development design of a motorcycle, reducing development time.

Why is fatigue analysis important?

Fatigue evaluations based purely on static FE analyses sometimes do not align with the results obtained from fatigue tests. In fact, in a structure subject to cyclic loading, the critical areas affected by fatigue phenomena can generally be different to those given by a simple static FE analysis. These differences can be more pronounced in welded structures, in which the welds are often the most fatigued areas.

Often the welds are modelled in FEA using shell elements. An important consideration in this scenario is that only stresses in the shell plan are provided by FEA. Therefore, if shell elements meet in two places, i.e. T-joints, one element will deliver an FEA stress, whilst the other element can only deliver zero value in the same place. When evaluating the total entity, the post processor generally averages the stresses at the neighbouring elements for every node. Therefore, the stress result displayed at any mutual node of these two elements will only be half of the actual stress.

RICARDO – Dyno Roller Bench Test

In FEA models, generally, the welded areas can produce unrealistic stress results, stress concentrations and singularities. The shape and size of elements near to the welded seams also have an influence on FEA results and can be affected by the geometry simplifications introduced in the transition areas and the replacements of radii with edges.

Difficulties can be correlated, based on necessity, by using specific standards to perform fatigue evaluation on a welded structure.

For example in the Eurocode 3 standard it is not easy to use the results provided by the FEA to evaluate the fatigue of welded seams for several reasons, including:

- finding the normal and transverse tangential stresses along all welding paths that are irregular.
- the coefficients to increase stress considering the details of the welds on both weld toe and weld root.
- the complex history loads
- choosing the right category representative to each welded seam.

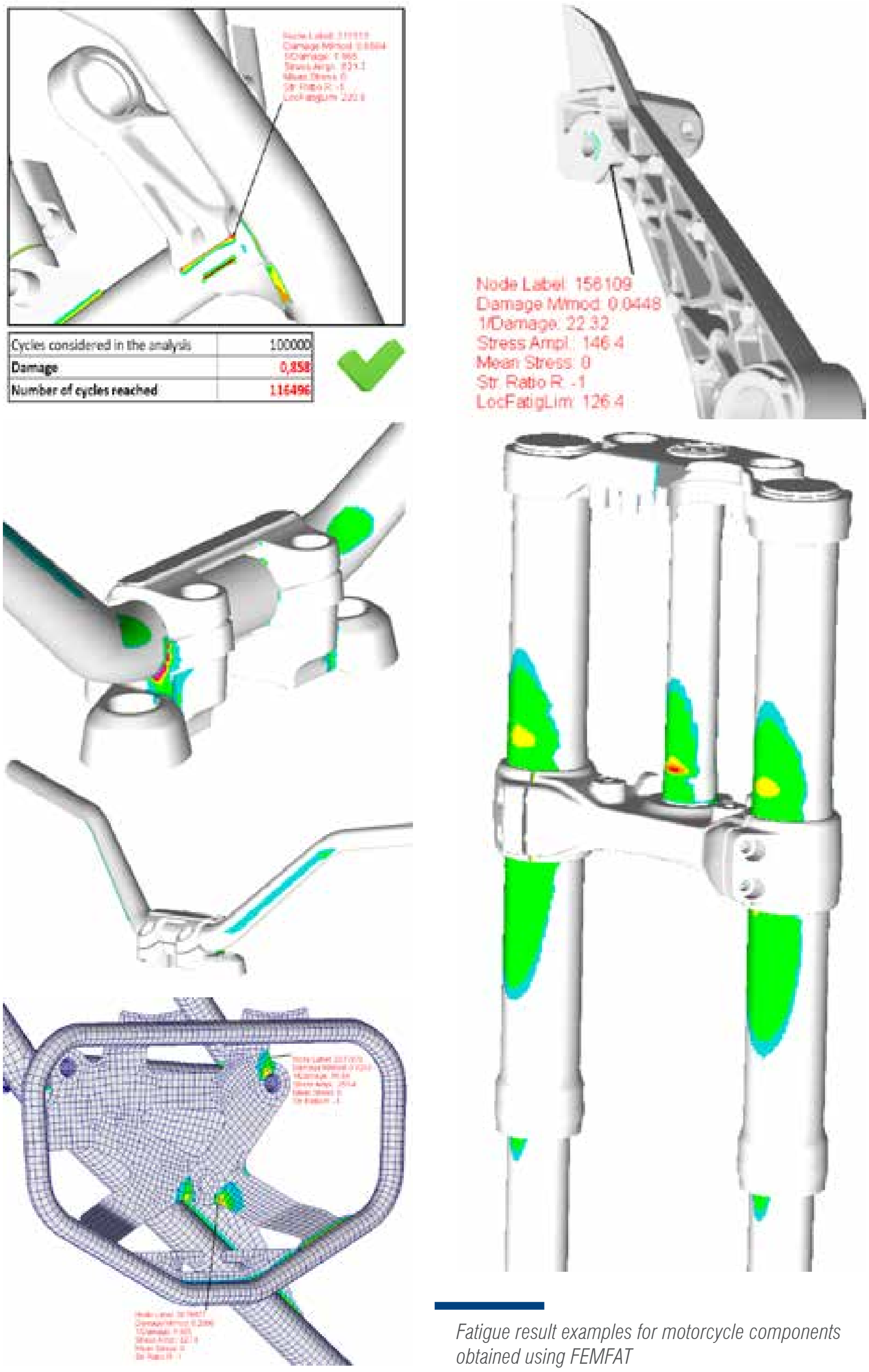
Dedicated, powerful and reliable software is essential to perform fatigue analysis. Ricardo mainly uses FEMFAT to perform these types of assessments, which helps to reduce risks in the process.

How does FEMFAT support fatigue analysis?

FEMFAT provides several resources to generate reliable fatigue analysis results through a series of modules, including:

FEMFAT Visualizer:

- Easily and effectively defines welds in the model according to one of the available standards. For example, Eurocode 3 for steel structures, Eurocode 9 for aluminium structures, BS7608 DVS952 and the ECS standard (FEMFAT 4.7), which is the best suited for motorcycles.
- Recognises the welds in the global FEA model even if they are complex in shape.
- Identifies the various joint types, weld types, and weld executions.



Fatigue result examples for motorcycle components obtained using FEMFAT

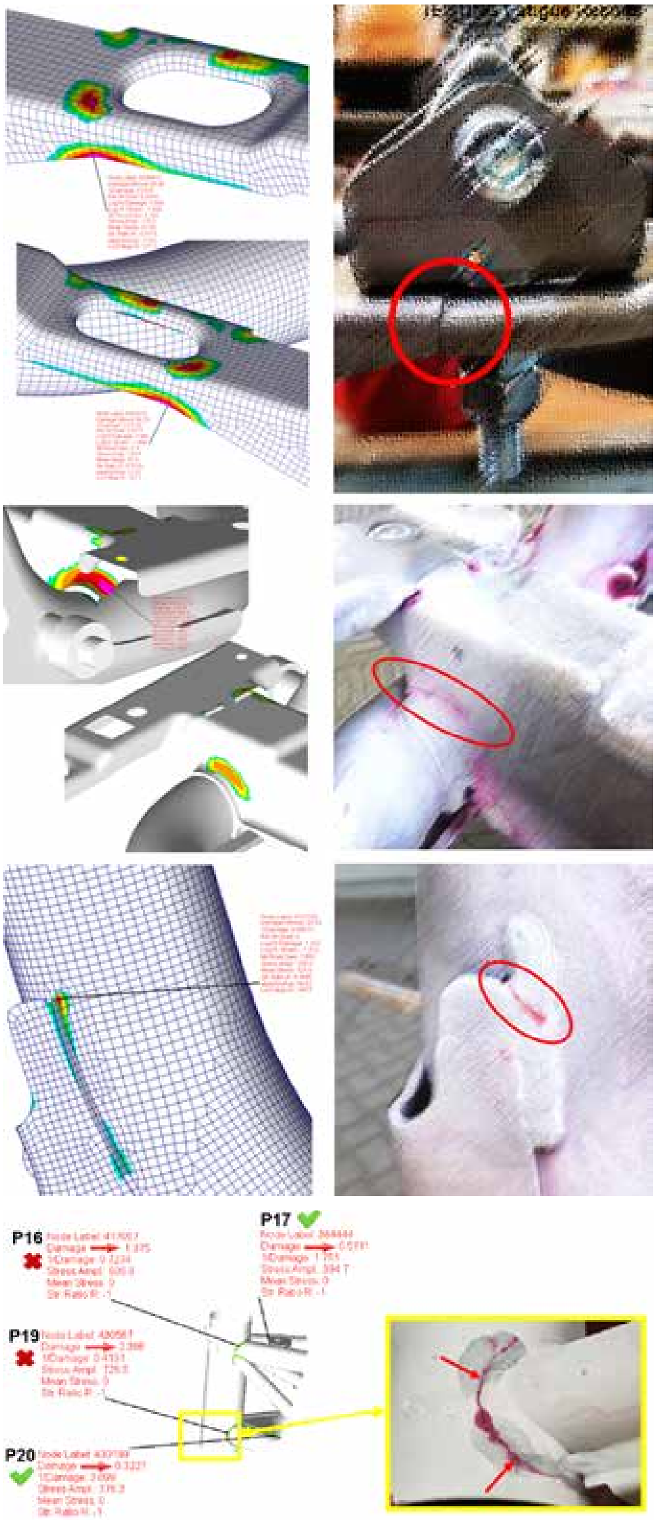
FEMFAT Weld:

- Evaluates structural stresses on the local welded areas of a component.
- Considers the “local stress approach” and the “structural stress method or hot spot method”, in the case of Eurocode 3, which is more suitable for the welded components of motorcycle and light mobility vehicles modelled using shell elements.
- Offers an “Automatic Stress Correction” option to minimize the effect of the size and quality of elements close to welded elements.
- Includes a “Compressive Stress Reduction” option to consider eventual stress reductions due to stress relief treatments applied to the welded structure after welding.
- Performs a fatigue assessment on the local weld regions, considering the relevant weld notch stresses at the root and toe of welds. Welded ends are treated separately due to their high notch effects.

FEMFAT allows users to consider all possible fatigue factors and perform a simultaneous evaluation of welds and the surrounding base material in a single analysis. The software creates the main outputs for fatigue analysis, including S-N graphs, Haigh diagrams, damage values and R (stress ratio).
Using FEMFAT enables Ricardo to determine the most relevant issues related to fatigue evaluations. For example, a factor of 3 or 5 (meaning an error between 200% and 400%) on the life estimation of a component could be considered in any case as a good correlation between fatigue simulation results and fatigue test results.

Conclusion

Ricardo uses FEA and fatigue analysis simulations combined with dedicated test bench and road tests to predict critical events. This helps the company to better support its clients in their goal of reducing project development time and go-to-market while maintaining the safety, quality, and confidence in each component.



Example of comparisons between fatigue results obtained using FEMFAT and testing results for some motorcycle components

About Ricardo

Ricardo is a global strategy, environmental and engineering consultancy listed on the London Stock Exchange. With over 100 years of engineering excellence and employing close to 3,000 people in more than 20 countries, we provide exceptional levels of expertise in delivering innovative and sustainable cross-sector outcomes to support energy transition and scarce resources, environmental services along with safe and smart mobility. Our global team of consultants, environmental specialists, engineers, and scientists supports our customers in solving the most complex and dynamic challenges to help achieve a safe and sustainable world. Visit ricardo.com

For further information on the motorcycle and light mobility services and solutions offered by Ricardo, get in touch with one of our experts info@ricardo.com

For more information about the software FEMFAT:

Paolo Bortolato - EnginSoft
p.bortolato@enginsoft.com

How digitalization can help decarbonize heavy industry: the BLOM Formula

by Matteo Bucchini, Tomasz Kaliciński, Tomasz Rudek
BLOM Maritime

The extensive use of steel makes this one of the most important industries in in our society. According to worldsteel.org, steel production has grown from 189m tonnes in 1950 to 1,951m tonnes in 2021.

The metal has a vital impact on society, employing 96 million people across the industry and its supporting structures, and on the global economy where it generates and facilitates a contribution of US$2.9 trillion [1].

Global environmental policy and ever-increasing limits on CO_2 emissions require ongoing improvements in efficiency and safety. This leads BLOM to make constant changes to its production systems, implementing new technologies with more advanced solutions and using 3D design tools such as Leica, AVEVA, Autodesk, or Bentley that offer a more efficient way of designing. 3D spaces allow designers to simulate on-site conditions and work in real-world situations, which helps enhance safety during installation, and saves time and money. However, before 3D technology can be used it is necessary to first create a digital twin of the facility.

Fig.1. Spheric view of a steel mill plant.

This does not simply mean using a point cloud as a three-dimensional digital representation of the object. Rather it means creating a complete information system to manage the data obtained during the scanning process, to design, and to install new systems and, most importantly, to support the team responsible for maintaining and operating the steel mill during continuous production.

We know from experience that scanning is just the beginning of creating an optimal solution and, one might say, represents the tip of the iceberg. However, being the initial stage of the process, BLOM uses state-of-the-art equipment, provided by Leica Geosystems [2].

The same can be said of managing costs during the lifecycle of a plant: where design influences approximately 1% of the cost over the entire lifecycle of the asset, operation and maintenance represent up to 70% [3]. BLOM's approach targets exactly this component:

The quality and completeness of the point cloud is, however, the most important factor affecting the quality of the other elements. In fact, it represents the fundamental starting point for most of our engineering projects.

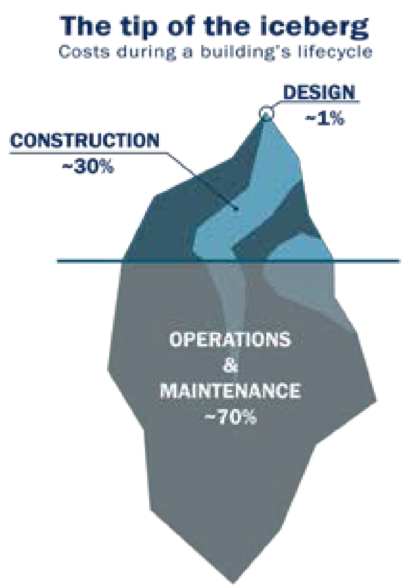


Fig.2. Costs during a building's lifecycle.

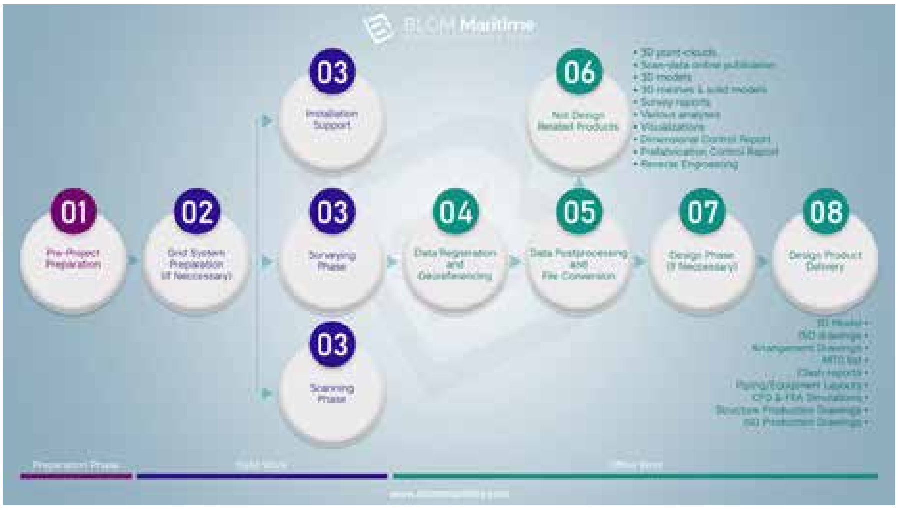


Fig.3. Standard BLOM Maritime workflow.

Ongoing collaboration in the metallurgical sector

BLOM collaborates openly with several major players in heavy industry. One of its partners is Mostostal Zabrze Biprohut. This company describes the project as follows:

"In 'design and build' projects on existing structures, knowledge of the actual condition of the facility is invaluable. The more information designers have about an object, the better they can adapt the design to the existing conditions and avoid potential problems during project implementation. A 3D design makes it possible to visualize existing conditions, to dimension objects that are difficult to access, and to perform a spatial analysis of potential clashes between newly designed objects and existing ones. 3D scanning has therefore become an indispensable tool for the designers at Mostostal Zabrze Biprohut.

"The structure scan that BLOM Maritime produced for us was an invaluable source of information for the design work associated with the recently completed renovation. Due to the size and complexity of the facility, the scan saved hundreds of designer hours that would otherwise have had to be spent on inventorying key elements. Furthermore, the ability to implement the scanning directly in the Biprohut design environment accelerated the entire design process by allowing newly designed process plants and steel structures to be created from scratch by building on their existing state. This significantly shortened the process of design verification and analysis before the design was released for implementation. The scan also helped the investor and other project stakeholders to visualize the newly designed solutions during discussions."

Other projects in European facilities

In other measurements for its partners, BLOM's engineers have performed more than 3,000 scans of different parts of facilities using LeicaRTC360 scanners. The point clouds were delivered in colour with the most important aspect of each measurement procedure being to define the clients' required elements very precisely. Despite the extent of every project, BLOM also took detailed measurements of specific critical elements, upon which 3D models were then created.

In order to achieve the objectives of decarbonization and the optimization of steel mills and furnaces, BLOM and its clients have jointly resolved to discontinue production of these system components. In one case, the plan is to build a new mini mill using two EAF (electric arc furnace) 9s to achieve the decarbonization milestones.

In this context, some materials such as scrap will be removed by trains and trucks. Other materials will be transported from

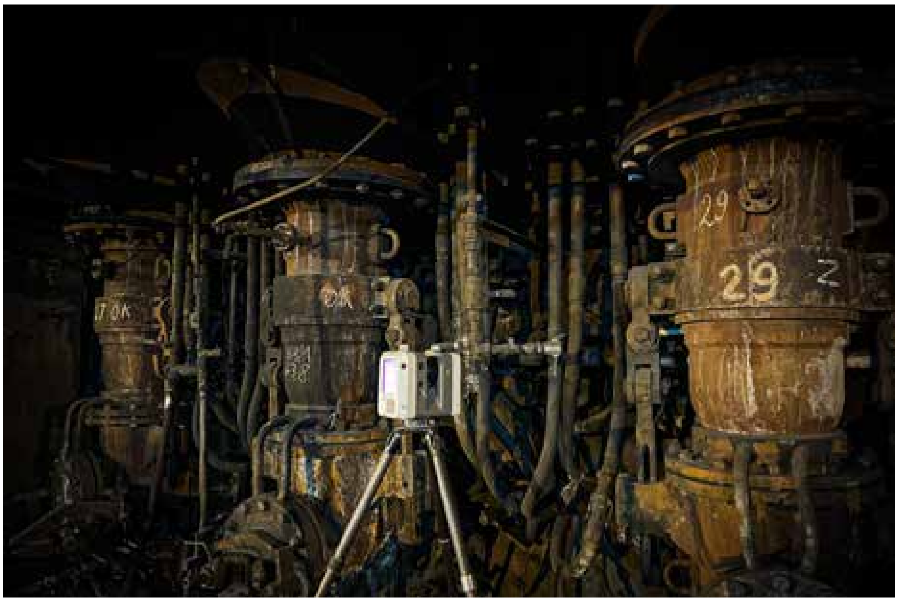


Fig.4. Scanning of the facility.

Fig.5. Survey engineer at the Brazilian Steel Mill

the storage areas to the new mini mill by conveyor. Specifically, HBI (hot briquetted iron), lime and dole, and alloys are planned to be transported to the EAFs via conveyors. To design these conveyors, BLOM's client requested complete scanning documentation of all the areas of interest including the landform, existing equipment, and roads.

To develop the required engineering, the client required:

- The details of the state of the scanned area.
- The ability to identify the possible collisions and non-ergonomic solutions.
- Highly accurate measurements of the distances (the scanner's permissible deviation in accuracy could not exceed ±3 mm for a range of 70 metres).

The Brazilian Steel Mill project in numbers.

- 3,000 colour scans
- 78,000m^2 covered
- 4-week scanning process
- 7 survey engineers involved
- 3TB of data delivered

Fig.7. Coloured 3D scan of the inside of the facility.

Fig.8. BIM model of the same area.

Steel mill scanning in South America

In a recent project at a steel mill in Brazil, BLOM performed the scan during a technical shutdown in order to access zones where there was a danger of gas leakage. While this created considerable challenges due to the high levels of staff activity, it did not stop our inspectors from completing the task.

Fig.6. Scanning survey of a steel mill.

A further challenge was coordinating the job with the various stages involved in overhauling the blast furnace which required some of its essential equipment to be dismantled. As a result, our engineers had to demonstrate great flexibility and availability in order to make optimal use of their time at the facility. The local visa requirements and customs duties added even more complexity to the project, underlining the fact that planning and logistics are key to success. Nevertheless, the successful outcome proved that everything is doable for BLOM.

The South America steel mill project in numbers

- 885 colour scans
- 12,000m^2 covered
- 2-week scanning process
- 2 survey engineers involved
- 5TB of data delivered

Digital twin of an aluminium plant in Norway

In the case of the Speira-Holmestrand aluminium plant in Norway, the measurement study involved the entire plant area including the office buildings. It required the creation of a survey grid together with GPS measurements. Work on site was performed at night when human traffic was reduced to minimize the danger to our engineers.

More than 6,000 scans were taken during the study to generate the point cloud from which the Building Information Modelling (BIM) was created in Autodesk Revit software. The model included all buildings with structures as well as the road infrastructure, all of which were executed in the LOD300 standard.
Figs. 7 and 8 compare the results of a 3D colour scan of an area and the BIM model of the same area created in Revit.

The Norwegian project in numbers

- 6,000 colour scans
- 165,000m^2 covered

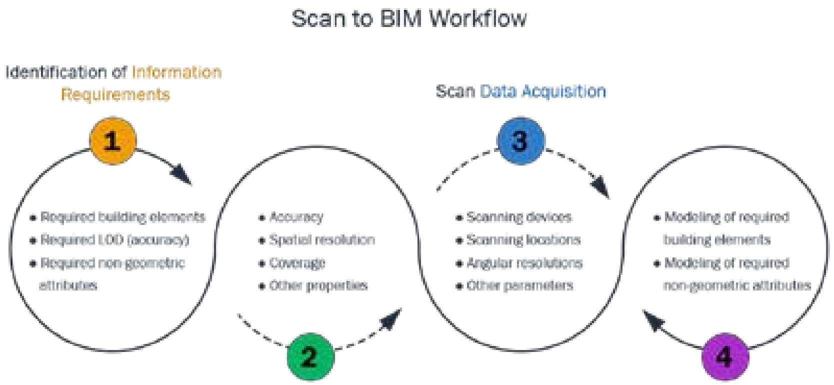


Fig.9. Scan to BIM Workflow Framework [4].

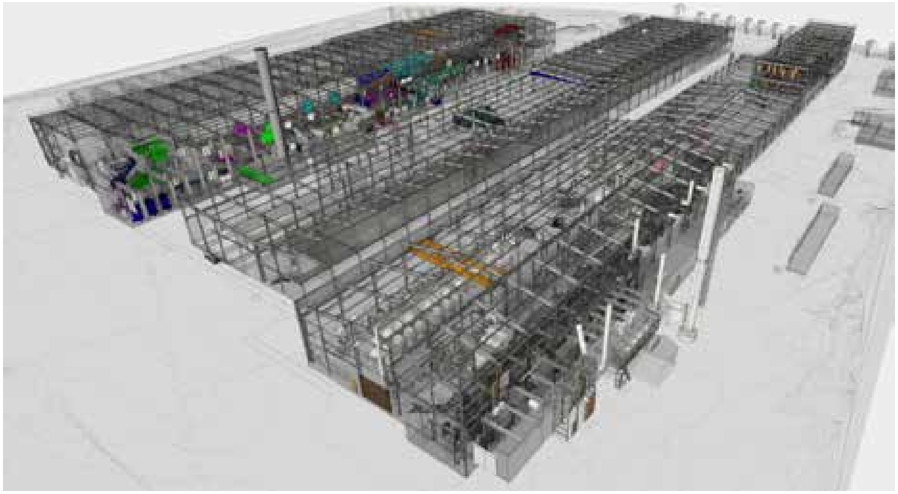


Fig.10. Steelmaking plant developed with a BIM approach.

- 3-week scanning process
- 6 survey engineers involved
- 2TB of data delivered

The BLOM Maritime approach

BLOM's main objective is to offer clients different solutions based on the Scope of Work provided. The company's approach is then defined by constant improvement and efficient use of data already in hand using the tools in each organization. In many cases, BLOM's team needs to think "outside the box" to simplify things, or to show opportunities that the client's users already have. Our flexible, cross-cutting technology which works with dedicated software accompanied by adequate planning as early as the measurement phase and the application of appropriate procedures delivers a rich set of results that exploits diverse possibilities for delivering the final product, such as data format, and the form of presentation. All these projects precisely follow BLOM's standard approach (see Fig. 9).

The Speira facility was a perfect example of the execution of this workflow: 3D scanning of the entire structure and the development of a BIM model with Revit. This approach gives BLOM a substantial number of possibilities to include precise information (BIM) about each 3D element from the paint colour and manufacturer, all the way to the assembly timeline (4D) stage and the cost of the modelled item (5D), unlocking so-called Level 2 BIM [5].

The key to success of the project is to provide "tailor-made" delivery taking into consideration the client's workflow and the hardware and software in use. We resolved this for Speira as follows:

- The point cloud provided the input data which was processed and prepared in Recap format, and oriented with global coordinates to facilitate interaction with Revit.
- The initial modelling stages. Accuracy, level of detail, and level of development were adjusted to the client's expectations and requirements. In most cases, the LOD300 standard is widely accepted. This approach provides a ready basis for updating, so that the client can decide what relevant information to store later.

As a result, this project has a level 1-2 maturity level: there is a common data environment, and the system is ready to develop to level 2 and, later, to level 3 [5] (see Fig. 11).

All BLOM's experiences with steel mill projects have had a common denominator: the enormous quantity of data involved. A project of 1,000 scans fills up to 70GB in Navis Works software. Computers with elevated computing performance, powerful graphics cards, and large, fast internal drives can be essential for working with laser scan data.

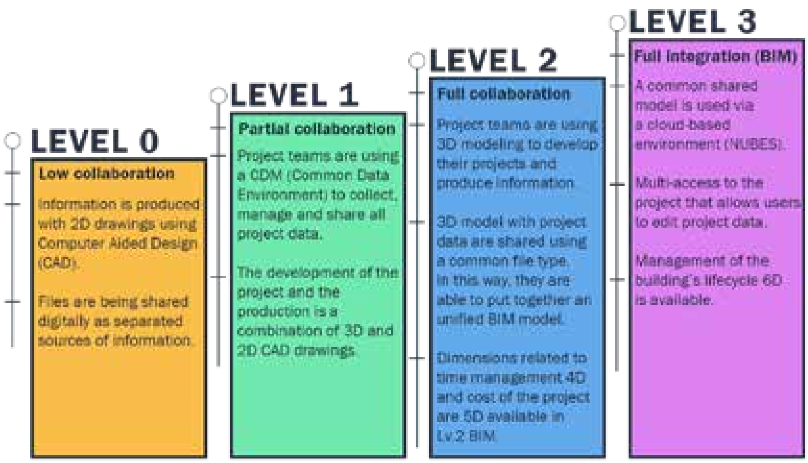


Fig.11. BIM maturity level.

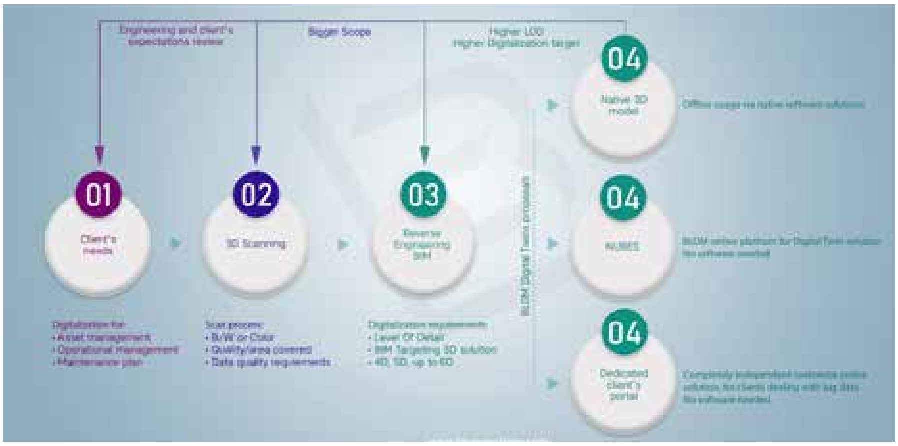


Fig.12. BLOM Digital Solution levels: native, NUBES or dedicated portal.

Fig.13. Online portal dedicated to Speira, map of a selection of buildings viewed from above.

NUBES: Visualization and Digital Twin

BLOM's answer to these high expectations is NUBES, the company's in-house online platform that offers the full range of possibilities in a single space, allowing multi-station point cloud work. NUBES is a complete solution that enables BLOM's customers to archive and view their point clouds and provides clients with full access to their data via the Internet from anywhere in the world. NUBES models are fully compatible with AVEVA software, so that clients can extract technical drawings, create annotations, and edit the point cloud and model.

BLOM also uses NUBES to train new employers or visitors. The detailed view of the site means that the company can conduct guided tours, and show risk areas and escape routes, etc. BLOM's crew will therefore be familiar with a site before they even enter it. NUBES also enables virtual reality (VR) experiences. Lastly, it does not require customers to make additional investments in software and hardware.

The latest addition to BLOM's suite of digital solutions is its dedicated client portal: where NUBES provides access to specific projects, this new dedicated portal allows BLOM to offer a completely independent customized online solution to clients dealing with big data and a high-level of discretization. The "Speira" portal, for BLOM's Norwegian client is an example of such a solution.

BLOM Maritime is proud to of its many years of experience working with companies such as Biprohut–Mostostal Zabrze, Speira, and many others. Our deep understanding of the prevailing conditions in steelworks and our long-term collaborations on extensive modifications to blast furnaces gives us the experience and ability to support our clients.

All our experience has led us to one conclusion: investing in the latest 3D technologies that optimally use the digital twin will determine the ability to develop, modify, and improve the efficiency of these complex industrial plants in the future. Our NUBES solution enables us to support steel makers in managing the large amounts of data obtained during design, installation and everyday operations. The ability to quickly and easily manage documents, easily access 3D documentation, visualize and share point-clouds, and most importantly, the continuous updating of collected data allows subsequent modifications to be effectively planned. Such complex systems require this type of holistic approach to optimize their lifecycle management.

For more information:
Marius Blom – BLOM Maritime
marius.blom@blommaritime.com

References

[1] worldsteel.org

[2] leica-geosystems.com/about-us/news-room/customer-magazine/reporter-78/reality-capture-for-bim

[3] autodesk.com/autodesk_university/class/_Getting_MEP_Designers_ready_for_BIM-2019#handout

[4] united-bim.com/resources/bim-infographics/

[5] www.buildingthedigital.com/blog/bim-beginners

About BLOM Maritime

BLOM Maritime is a leading global provider of 3D digital data acquisition and engineering solutions for the marine, offshore and power sectors. We specialize in capturing and optimizing data 'as-is' for better engineering and project execution. We provide a full-cycle service ensuring that cost-effective solutions are continuously implemented before, during, and after projects. We are part of the TECO Maritime Group. Our subsidiary offices, together with business partners, are strategically positioned around the globe to ensure rapid response and reliable service. The entire network of subsidiaries and strategic business partners employs more than 170 people worldwide. To date, we have completed more than 3,000 projects, across the various industries we serve.

Fig. 1. Multi-process autoclave.

Boosting CFD simulation of thermal equipment for food processing

by Javier Porto[1], Mónica González[2], Leopoldo Álvarez[3], Ana Palmero[4], Andrés Gómez[5]
1. SDEA Engineering – 2. TACORE – 3. ANFACO-CECOPESCA – 4. INEGI and Faculdade de Engenharia da Universidade do Porto (FEUP) – 5. CESGA

The challenge: developing a specialized tool to simulate thermal sterilization processes in autoclaves

In Europe, the canning industry is important economically, particularly in Spain which is the leading producer of canned fish in Europe, and in Portugal, which is among the top five producers of canned goods. Some of the most energy-consuming processes are the thermal treatments applied in autoclaves for product sterilization, therefore any tool that improves these processes will reduce both energy consumption and CO2 emissions and save costs in the food production chain.

The inherent complexity of the concepts involved in fluid-thermal simulation engineering means that simulation work currently requires the involvement of highly trained and specialized personnel well-versed in these methodologies.

Moreover, the commercial simulation tools currently on the market take a generic approach that makes the representation of the various geometries and operating conditions time-consuming. It is thus a costly endeavour to test products before manufacturing new equipment or putting recipes into production. Therefore, the challenge is to develop a specialized tool to simulate thermal sterilization processes in autoclaves. Fig. 1 shows an autoclave in which multiple processes could be developed. This experiment was developed to address this challenge using technologies such as high-performance computing (HPC) and computational fluid dynamics (CFD) simulation.

From a business perspective for the companies involved in the experiment, this challenge was their first experience with HPC services and, therefore, represented an opening to new competencies and opportunities.

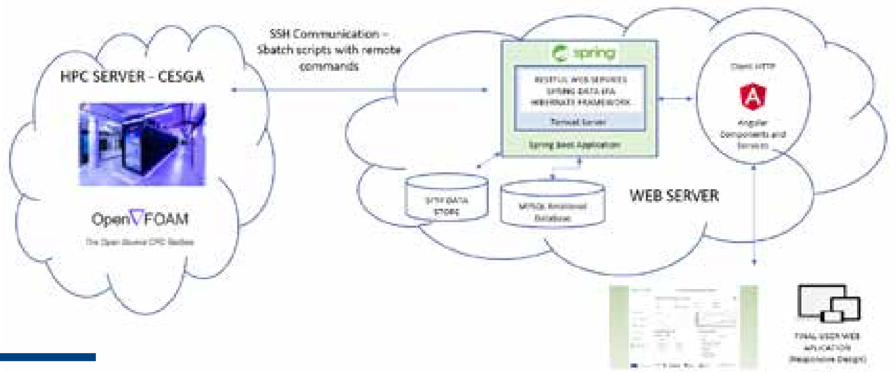


Fig. 2. Web GUI architecture.

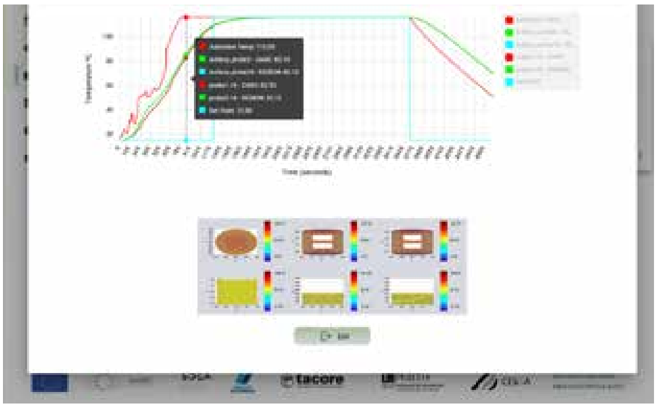


Fig. 3. Simulation example.

The solution: simulation of an autoclave

One solution is a tool specifically for simulating thermal sterilization processes in autoclaves; this tool is a complete SaaS (software-as-a-service) that includes HPC resources and is offered to customers on a subscription basis including all services. It consists mainly of two parts: the simulation model developed using OpenFOAM and executed on the HPC platform, and the Web GUI (graphical user interface) that has the architecture shown in Fig. 2. This application allows users to run simulations of an autoclave, configure certain parameters, and monitor the evolution of the simulation. It also permits the company to analyse previous simulations and compare them with each other.

Without HPC it would take 3–5 hours to run each simulation, which is too long for a good end-user experience. The use of HPC enables autoclave manufacturing companies' end users to run simulations in more detail in less time (between 5–15 minutes per simulation), allowing users to test different cases in a short time.

Fig. 3 shows an example of a simulation output. This Web GUI has the following parts: Login and Registration; Simulation History; Visualization; Simulation and Billing; and Analysis and Configuration. The CFD model, developed with OpenFOAM, has the following features:

- Case study: heat transfer problems between multiple regions
- Mesh: unstructured 3D
- Number of cells: ≈ 1,104,450
- Solver: chtMultiRegionFoam
- Partition method: hierarchical and Scotch

This model is configurable allowing the user to modify more than 30 parameters of the sterilization process, and it was configured to solve the simulation by parallelization to take advantage of the HPC resources, as can be seen in Fig. 4.

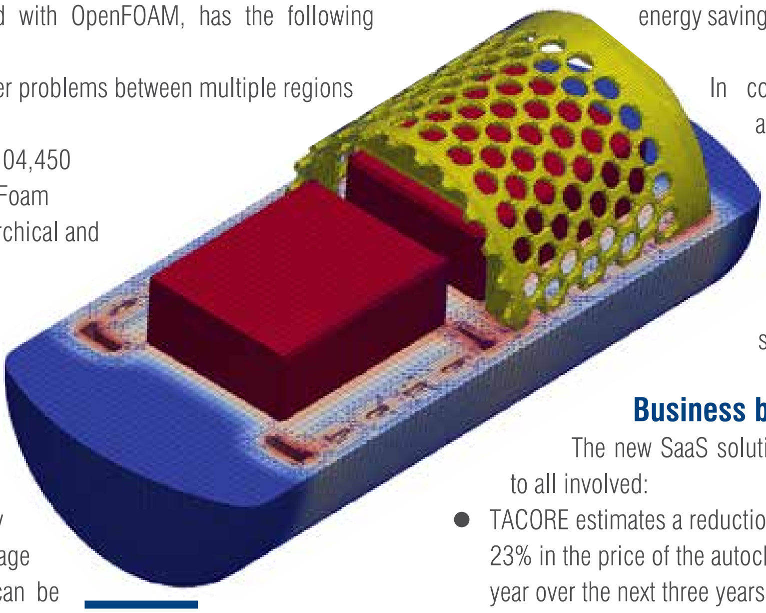


Fig. 4. Simulation mesh.

After validation, some conclusions can be drawn:

- Compared to the use of a computer with comparable medium-level computing resources, execution time was reduced by 90% to processes of 5–6 minutes (300–360 seconds) in length (Fig. 5).
- It seems to establish a knee on the acceleration curve with the following factors: 1 core per task; 48 MPI tasks per node; 8 GB RAM per node.

The results of simulations and validation tests were analysed and the flow rates, pressures, and temperatures of the different fluids in autoclave were studied. This investigation made it possible to compile the energy balance for using the autoclave for sterilizing processes, including the calculation of consumed energy and CO_2 emissions in the final solution, and the effect of including a heat recovery unit in the autoclave.

The SaaS solution: delivering adequate business benefits and significant environmental impact

With the help of the new SaaS solution, partners involved in the experiment could plan their first outputs. TACORE, the end-user in this experiment, gains an advantage in the market from having more efficient and customizable manufacturing. Reducing the costs to develop an autoclave facilitates the replacement of obsolete equipment, leading to an annual saving of €40,000.

For SDEA, the independent software vendor, the new opportunities created will see them incorporating a specialized profile to develop and support the SaaS. The Faculty of Engineering of the University of Porto will introduce this tool to its students as a showcase of the applications with potential for energy optimization. Using this tool, the students can gain knowledge on saving CO_2 emissions.

ANFACO, the technology expert, is using this opportunity to offer a new tool to industries that could apply the new services to their production processes and gain a commercial advantage in terms of energy savings and reduction of CO_2 emissions.

In conclusion, the simulations and analysis of the experiment will provide detailed information on the energy consumption of a machine and identify whether it is possible and useful to take action to reduce it, resulting in a smaller carbon footprint.

Business benefits

The new SaaS solution provides commercial benefits to all involved:

- TACORE estimates a reduction in production costs of around 23% in the price of the autoclave, (less than €100,000 per year over the next three years) representing an annual benefit of 2.7% of the average annual revenue.

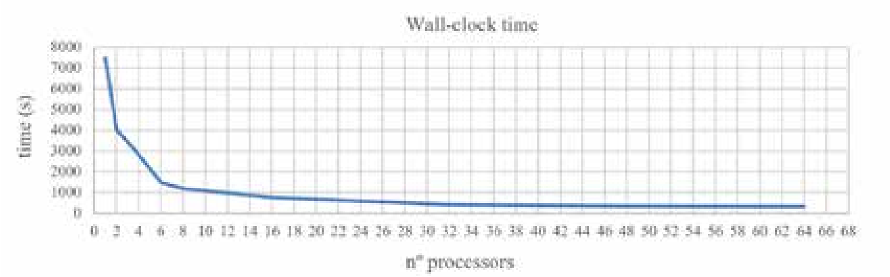


Fig. 5. Clock time vs. number of processors.

For more information:
Tina Crnigoj Marc - Arctur
FF4EuroHPC Communication lead
ff4eurohpc@hlrs.de

- Cost and energy savings for food companies (ANFACO members and other companies) – an efficiency improvement of 2% would mean a saving of 0.00187592 tCO_2/tonne of processed product.
- SDEA estimates an annual income of €40,000–€60,000 for developing a customized application for each new customer opportunity.
- For the Faculty of Engineering of the University of Porto, as an education organization, the main benefit is having a new tool for academic activities and the knowledge gained on HPC and autoclave thermal processes.

This success story was developed during the second tranche of FF4EuroHPC, which supports the competitiveness of European SMEs by funding business-oriented experiments and promoting the adoption of advanced HPC technologies and services.

The experiment is an end-user-relevant case study demonstrating the use of cloud-based HPC and the benefits it brings to the value chain, from the end-user to the HPC-infrastructure provider, thus addressing the business challenges of SMEs by using HPC and complementary technologies such as HPDA (high performance data analytics) and AI. When the experiment is successfully concluded, the result is a success story that inspires the industrial community.

The FF4EuroHPC project has received funding from the European High-Performance Computing Joint Undertaking (JU) under grant agreement No. 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and from Germany, Italy, Slovenia, France, and Spain.

The success story presented in this article was developed during the first tranche of FF4EuroHPC Project. FF4EuroHPC supports the competitiveness of European SMEs by funding business-oriented experiments and promoting the uptake of advanced HPC technologies and services. The experiment is an end-user-relevant case study demonstrating the use of cloud-based HPC (high-performance computing) and its benefits to the value chain (from end-user to HPC-infrastructure provider) for addressing SME business challenges that require the use of HPC and complementary technologies such as HPDA (high performance data analytics) and AI (artificial intelligence). The successful conclusion of the experiment created a success story that can inspire the industrial community.

A Journey through Digital Lung Models

The Lung Modelling Congress (www.chiesi.com/lung-modelling-congress/en/) jointly organized by the Centre of Open Innovation & Competence (COI&C) and R&D Digital's Data Modelling Department, took place from November 22–23 at the Chiesi Group Headquarters in Parma in Italy. It gathered together international experts in the simulation of patient airways and respiratory system digital twins from the USA, New Zealand and Europe.

Academics and start-ups shared their best practices, exhibited various excellences, and challenged the current status quo with a roadmap for future developments. The extensive participation and debate confirmed the enormous potential of mathematical models and simulations to shorten time to market, reduce product development costs, personalize real-time diagnoses, and put the patient at the forefront.

This application obviously requires multi-sectoral expertise from various professionals ranging from physicists, mathematicians, and data scientists to pulmonologists and fluid engineers. Open and multidisciplinary events such as the Lung Modelling Congress are therefore key tools for the different communities of researchers and companies to plan future developments in a collaborative and unified manner.

Apart from the design of pharmaceutical products, the development and validation of computational models of the human respiratory system could have a great impact in many areas of healthcare, safety and the environment.

A digital twin of airflow and inhaled drug delivery in a human airway

by Bart De Jong[1], Leonardo Geronzi[2], Marco Evangelos Biancolini[2], Benigno Marco Fanni[3], Simona Celi[3], Gerben Roest[4], Sasa Kenjeres[5]

1. One Simulations – 2. RBF Morph – 3. Fondazione Toscana Gabriele Monasterio – 4. GrepIT – 5. TUDelft

Respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) are caused when parts of human airways become narrower. Medical treatment for these diseases involves the patient inhaling drug particles. Some patients experience uneven distribution of the drug particles, resulting in ineffective treatment, increased side effects and wasted medication. At present the deposition of inhaled drugs is studied by having the patient inhale a radiolabelled drug, however, this exposes the patient to a certain level of radiation.

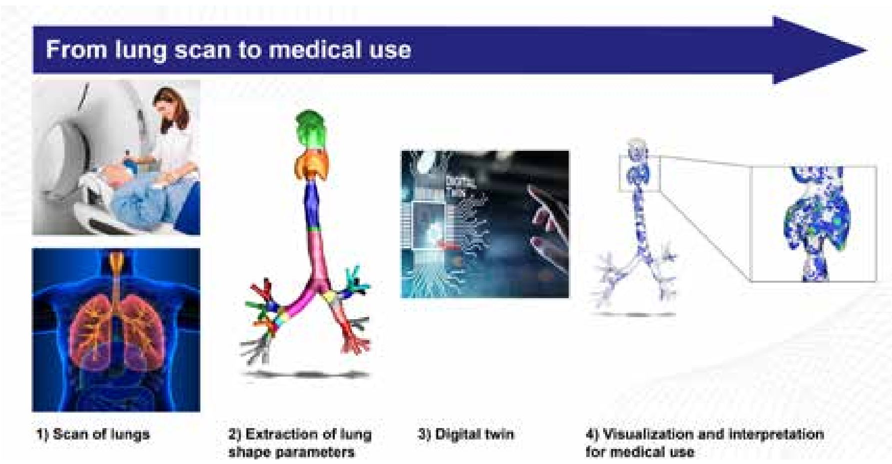


Fig. 1. The concept of the DiTAiD experiment. From left to right: the shape of the patient's lungs is acquired by the scanning device; the image data is processed and the shape parameters extracted; these parameters are used as input to the digital twin of a human airway resulting in a real-time visualization allowing interactive selection of the treatment strategy.

This FF4EuroHPC experiment aims to provide an alternative method whereby a detailed CFD (computational fluid dynamics) simulation is made of the patient. However, conducting a CFD study for each patient would be too complex and time-consuming since it relies on manually creating a 3D model from a CT scan. Even for a CFD expert with access to an HPC (high-performance computing) system, each study would take several weeks to complete, which represents a serious disadvantage for urgent medical cases. The associated costs would also be high.

The solution developed as part of this experiment is an easy-to-use digital twin (DT) that can predict the particle deposition of inhaled drugs in any human airway (Fig. 1). The DT is based on a reduced order model (ROM) that uses mesh morphing technologies on the basic geometry of a human airway to generate 1,000 models of a human airway and then simulates particle deposition using CFD on a 960-core HPC system. The simulation results are compressed into an ROM, which dramatically reduces the complexity of large-scale numerical simulations while maintaining a good level of detail.

To use the DT, a medical image of the patient's airway is fed into the software, which then automatically extracts its shape parameters and reproduces the results of a CFD analysis from the ROM to assist in optimizing the particle size – all in one click and avoiding time-consuming and expensive CFD workflows.

The challenge: creating a predictive digital twin for a human airway

This ambitious endeavour consisted of four major steps (Fig.2), each contributing significantly to the ultimate goal of revolutionizing our understanding of respiratory dynamics and enhancing patient care.

Data preparation and parameter identification

This phase focused on selecting a base geometry of a human airway. To ensure the DT's versatility and applicability to a wide population, the airway was defined using a comprehensive set of shape parameters.

These parameters include vital aspects such as curvature radius, diameter, bifurcation angles, branch lengths, and more. Another equally essential aspect is identifying the flow and particle parameters that are crucial for calculating flow patterns and particle deposition within a human lung. These parameters include inhalation velocity, particle diameter, and particle injection velocity (Fig.1 and Table 1).

Parametric study and data generation

Once the baseline in-silico model representing a generic patient was defined, it had to be prepared for HPC to generate the data required to train the digital twin. A parametric analysis was needed to provide the essential data required to create the ROM and DT.

This phase began with the development of a morphing script, based on RBF Morph technology, to deform the base lung geometry using the shape parameters identified. Simultaneously, a CFD setup was meticulously created in Ansys Fluent for the basic geometry. A rigorous validation study of the CFD setup was conducted in which the CFD results were compared with existing literature. The sensitivity of various parameters, including mesh sensitivity, the number of particle streams to be injected, and other numerical settings were studied.

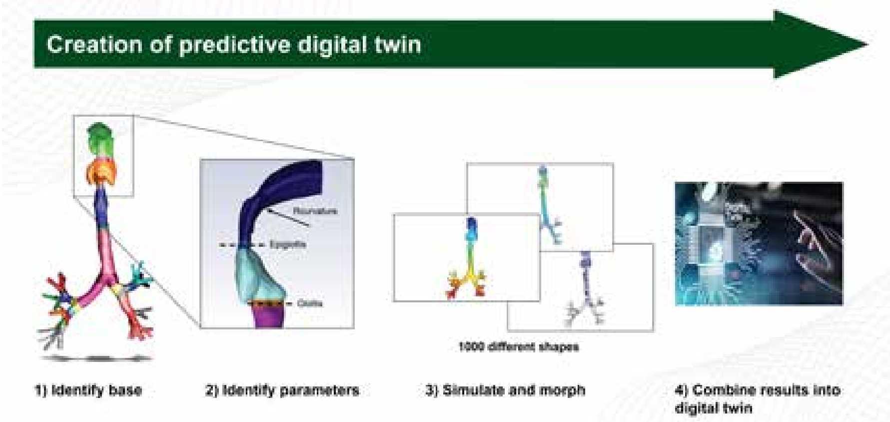


Fig.2. Details of the DiTAiD workflow. From left to right: a basic CFD representing the geometry of an average patient's lung is defined; the geometric parameters of the human airway are identified; mesh morphing is used to study 1,000 different virtual patients; the results obtained are finally combined to create a digital twin that is suitable for representing a specific new patient.

Once these preparatory steps were completed, a substantial number of CFD simulations – commonly referred to as "snapshots" – were set in motion on an HPC cluster. Each snapshot simulation adapts the basic geometry and mesh to the patient's shape parameters via the morphing script. In addition, the flow and particle input parameters vary for each snapshot within the specified range, following the DoE (design of experiments) table created with the Latin Hypercube Sampling algorithm.

To ensure the quality and reliability of these simulations, an automated script was used for rigorous quality assurance. This meticulous approach eliminated poorly converged runs, paving the way for the subsequent creation of the ROMs.

ROM creation and DT assembly

Once the simulation dataset was generated, the resulting snapshot simulations had to be distilled into invaluable ROMs. Using Ansys Twin Builder, the simulation results were assembled into self-contained ROMs. The

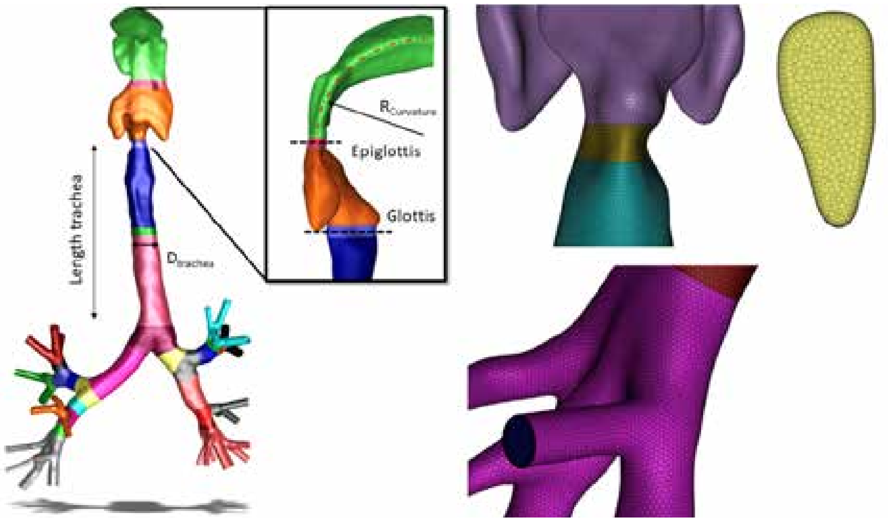


Fig.3. The baseline geometry (left) and its CFD mesh representing a generic patient, ready to receive the parameters of a specific new patient.

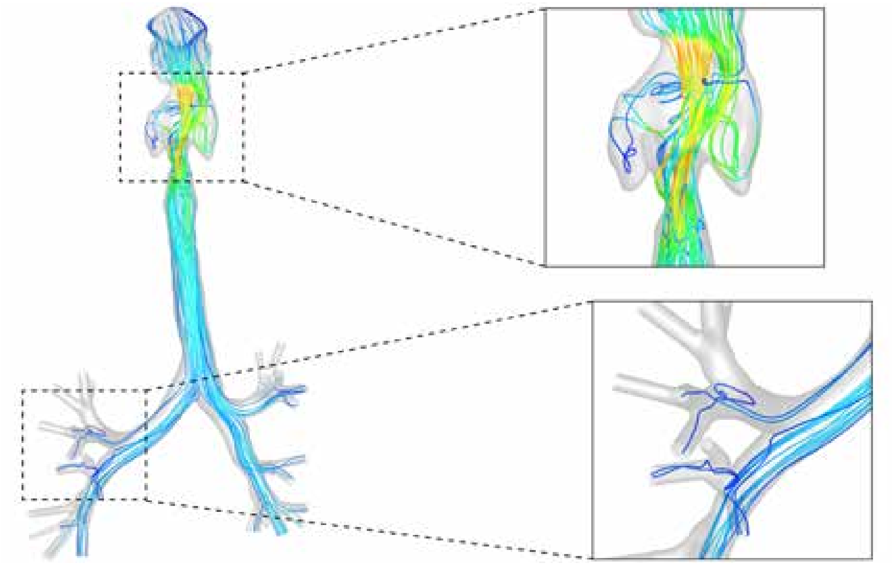


Fig.4. Details of the flow field in a human airway captured by the high fidelity CFD model used in the experiment to represent a generic patient and ready to be adapted to the shape of a specific patient.

accuracy and fidelity of these ROMs were assessed via a rigorous comparison with high-fidelity snapshots. Surprisingly, this comparison revealed minimal differences between the high- and low-fidelity models and those primarily in regions of flow separation, such as near the throat.

The individual ROMs, fast-response models that provide specific flow and particle information, were subsequently amalgamated into a single cohesive digital twin. To facilitate interoperability with other software applications, FMU (functional mock-up unit) files were generated to create an adaptable and robust DT of the human airway.

Revelatory achievements: converting human airways into a predictive digital twin

We began by selecting a fundamental geometry, which was then meticulously prepared for modelling and morphing by CFD. The results are illustrated in Fig.3, which also highlights several key lung shape parameters. The mesh details are also shown.

This process identified a total of 26 lung-shape parameters, each associated with specific ranges of values. The parameters relating to the region of the mouth and throat include the curvature of the throat, the epiglottis, and the glottis. The remaining parameters include the diameter of the trachea, its length, and various lengths and branching angles within the lower portion of the lung.

To streamline the input parameters, we adopted a fixed ratio from the existing literature for the trachea's diameter in relation to the diameters of subsequent branches. Furthermore, we identify three input parameters linked to airflow and drug-particle behaviour: inhalation flow rate, particle diameter, and particle injection velocity. The inhalation flow rate varies between 15L/min and 120L/min, particle diameter fluctuates between 0.1μm and 10μm, and particle injection velocity ranges from 0m/s to 10m/s. An overview of these input parameters and their respective ranges can be found in Table 1.

To achieve optimal spacing between snapshots, a DoE table for 1,000 snapshots was generated using the Latin Hypercube Sampling algorithm.

To create the morphing script, we first extracted the airway centrelines and calculated the shape parameters of the base geometry. Using radial basis functions and the information collected, we transformed the base geometry, thereby generating a new CFD model of a human airway based on each set of shape parameters. In addition, the morphing script generates PTS files that contain the coordinates for each node of the original mesh created using the base geometry along with the node displacements. These PTS files are pre-generated for the entire DoE table and govern the morphing process during the parametric study.

After completing the DoE table, 1,000 CFD jobs were sent to a rented HPC cluster. This cluster consisted of 8 nodes, each with 120 cores, totaling 960 cores for calculations. The purchased Ansys license allowed for 25 simultaneous runs. Unfortunately, 40 runs of the 1,000 submitted jobs failed, and three runs showed poor convergence or unphysical results. These failures were mainly caused by the presence of cells with negative volumes that were generated during the morphing process.

Region of mouth and throat				
$R_{curvature}$ [cm]		2-8		
Epiglottis area [mm^2]		40-400		
Glottis area [mm^2]		40-400		
Region of lower airways				
Generation	**Diameter [mm]**	**Length [mm] Left**	**Length [mm] Right**	**Branching angle [deg]**
0 (Trachea)	15-50	100-120		80-95
1		51-57	24-28	75-90
2		12-16	15-28	65-95
3		7-10	7-10	55-70
Physical parameters				
Flow rate [L/min]		15-120		
Particle diameter [μm]		0.1-10		
Injection velocity [m/s]		0-10		

Table 1: Overview of input parameters and their ranges.

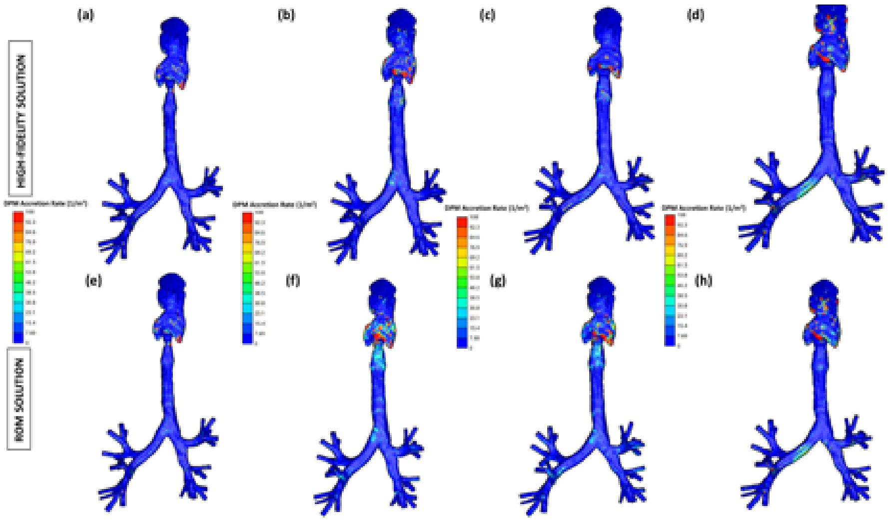


Fig.5. Particle deposition comparison between the high-fidelity CFD simulations (a-d) and the ROM solutions (e-h) for four different virtual patients corresponding to four sets of input parameters.

The snapshot output included data on particle deposition, wall shear stress, velocity, pressure, turbulent dissipation rate (ε), and turbulent kinetic energy (k). For each of these variables, we constructed a ROM. This ROM can calculate results for any combination of the previously defined input parameters, even for combinations that were not simulated in great detail. We quantified accuracy through leave-one-out cross-validation by comparing the low-fidelity ROM results with high-fidelity CFD snapshots not used in ROM creation.

Fig.5 presents a comparison between the CFD and ROM results for drug particle deposition. It reveals the locations in which drug particles are deposited in a human airway in four different scenarios, each characterized by distinct combinations of input parameters resulting in different lung shapes, flow conditions, and particle sizes. The top row shows the results obtained from a CFD simulation, while the bottom row illustrates the results derived from the ROM. The comparison shows minimal differences between the two sets of data. Despite the slight disparities, a ROM can provide results at the push of a button, whereas a full CFD simulation may require weeks. Finally, we consolidated the individual ROMs into a single DT, which was exported in FMU-file format to be accessible by other software applications.

In conclusion, this FF4EuroHPC experiment achieved a ground-breaking milestone in medical science, particularly for the treatment of respiratory diseases such as asthma and COPD. By developing an innovative DT of a human airway, this experiment addressed the critical challenges associated with uneven distribution of inhaled drug particles in patients; exposure to radiation from drug deposition studies; and the time and cost constraints of traditional CFD simulations.
This solution, based on a ROM and mesh morphing technologies, created a versatile and user-friendly tool that can predict particle deposition for any human airway. By automating the process of extracting the shape parameters from medical images, this DT eliminates the need for time-consuming and expensive CFD workflows. This result significantly accelerates the optimization of treatment strategies and improves patient care, particularly for urgent medical cases.

The impact of this research on the medical sector cannot be overestimated. The ability to efficiently and accurately predict drug particle deposition in patient airways not only reduces treatment inefficiencies and side effects, but also minimizes radiation exposure, a significant concern in healthcare. Furthermore, the accessibility of the DT in FMU-file format allows seamless integration with other medical software applications, facilitating collaboration and further research in the field of respiratory medicine.

In essence, this experiment has paved the way for a transformative shift in respiratory medicine by representing human airways in predictive digital twins. This achievement holds great promise for improving the lives of patients suffering from respiratory diseases and underlines the invaluable role of advanced computational modelling in advancing healthcare practices.

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For more information:
Tina Crnigoj Marc - Arctur
FF4EuroHPC Communication lead
ff4eurohpc@hlrs.de

Design and impact assessment of a die-casting insert made with Additive Manufacturing

by Filippo Voltazza[1], Stefania Bruschi[2], Rachele Bertolini[2], Nicola Gramegna[3], Giampietro Scarpa[3]
1. Saen - 2. Università degli Studi di Padova, DII - 3. EnginSoft

The challenges for the manufacturing sector, and in particular for the light alloy die-casting sector, are manifold. Being competitive in dynamic environments requires rapid product innovation and consequently, the rapid adaptation of production systems. A structured, integrated and easily reconfigurable system is required to create more responsive and agile production lines which integrate with robust supply chains that supply the necessary materials, tools, and resources to respond effectively to emergency situations such as pandemics. A good example is an additive manufacturing system that enables both the production of small batches and the ability to make rapid changes to dies and tools in response to individual customer demand or to replace damaged parts. A high-quality agile production system must guarantee the reliability and performance of the products it produces before they are sent to market. Lastly, an efficient and safe production line requires the rapid reconfiguration of processes in order to maintain extreme competitiveness with equivalent quality/functionality and work security.

In response to these challenges, this paper presents a summary of some of the significant results obtained in the metallurgical part of the Veneto region's AGILE project. Digitalizing the design phase transforms, systematizes, and virtualizes design, making it faster and more flexible and enabling it to become a company "asset" that can be improved as contexts and scenarios change, all of which strongly support competitiveness.

The solution described in this paper was introduced into one of the aluminium alloy high-pressure die-casting (HPDC) foundries of one of the project partners (Saen) and used various simulation tools to redesign both the HPDC process and a die to accommodate the insertion of an insert with conformal channels made with additive printing in H13 steel. The die-casting simulation optimized the shape of these channels and of the process parameters in order to maximize heat removal in the massive zone of the casting, thus reducing the risk of defects. At the same time, the simulation enabled the prediction of the thermo-mechanical behaviour of the insert, and of the entire mould, both of which are crucial for estimating the fatigue life of the insert itself.

SCOPE OF THE PROJECT
Agility in high-pressure die-casting (HPDC)

The foundry sector, and particularly the die-casting sector, has undergone an evolution over the last ten years that is gradually transforming it into Foundry4.0, and increasing numbers of the enabling technologies of Industry4.0 are being integrated into the design and management of production systems.

It is widely acknowledged that the heart of die-casting lies in the mould or die that, together with the press, represents the essential equipment necessary to mass-produce numerous light alloy castings. Notwithstanding the consolidated use of simulation in the design phase, and a marked increase in process control, the agility of the die-casting process is significantly affected by slow product-code changes, the inability to economically produce small-batch production runs, and the lack of intelligent tools to control production and final quality: all aspects that were made even more apparent by the pandemic.

There are four strategic approaches that can be taken to create a highly automated yet highly operator-dependent and mass-production-friendly process more agile:

- The virtualization of the design phase transforms, systematizes, and virtualizes design, making it faster and more flexible and enabling it to become a company "asset" that can be improved as contexts and scenarios change, all of which strongly support competitiveness;
- The implementation of advanced and high-speed manufacturing technologies, such as additive manufacturing (AM), that allow completely new components or totally reconceived equipment and/or parts to be produced quickly and easily;
- The rapid reconfiguration and optimization of the production process by rendering equipment and process parameters as flexible as possible;
- Intelligent quality management focused on zero defects but with increased attention to productivity, tool life, and time to market.

Broadly speaking, "agility" should increase the skills, boost the production, and enhance the market competitiveness of all the companies in the light-alloy foundry industry, Italy's leading production sector in Europe.

Design of an HPDC insert with conformal cooling channels

Issues of thermal fatigue and the consequent damage to the die, and deteriorated casting-surface quality, or alloy-to-mould bonding, which requires an interruption of the production cycle for maintenance, are more likely to occur in zones where it is more difficult to thermally control the mould.

The use of "plugs" and "inserts" to maximize mould life and productivity was introduced some time ago. These are components, frequently made of higher-quality materials that better resist thermal stresses, which are incorporated into the mould. Plugs and inserts are generally produced by machining from bar stock, but this approach limits the ability to implement and/or optimize internal cooling circuits.

The recent growth in interest in the use of Additive Manufacturing to create these inserts and/or plugs is therefore easily understandable, particularly considering that AM guarantees two options:

Fig. 1. Test case: SEG Automotive's Boost Recuperation Machine (BRM) system – one of the leading 48V machines on the market and already deployed in over one million vehicles on the road across the globe.

- the use of selected, high-performance materials where they are most needed while continuing to make the other parts of the mould with more conventional steels and materials;
- the creation and inclusion of "customized" cooling circuits to optimize the operation and duration of the entire mould, as well as to ensure the consistent quality of die-cast products.

The features of SEG Automotive's BRM system can be summarized as follows:

- It allows rapid, silent, immediate, and reliable engine start;
- It stores charge in a 48V battery from which it provides the electricity to power the car's 12V systems via a DC/DC converter;
- The kinetic energy created by braking is converted into electrical energy and stored in the battery;
- During acceleration, it provides additional torque to the thermal engine;
- At constant cruise speed, the BRM system maintains the vehicle's speed with the engine off in "free-wheel" mode and consuming zero fuel;
- Upon renewed acceleration, the system instantly starts the engine;
- Traditional start-stop functionality.

The cover/housing product development phase involved an initial numerical simulation that was conducted with MAGMASOFT, after which some die-cast prototypes were produced. These processes revealed some critical issues in the porous zones where the BRM attaches to the engine. To reduce the incidence of the problem, we studied an insert with specially designed thermoregulation channels to be inserted in the critical area. Thermal simulations were used to define these thermoregulation circuits (see Fig. 2). The small insert (30mm x 30mm x 60mm) was optimized by developing specific geometries for the thermoregulation channels that are impossible to achieve with traditional machining. AM technology, however, allowed us to create channels with extremely narrow diameters (2mm) and curved flow trajectories, "free" from any of the restrictions of traditional machining. This enabled us to significantly optimize the insert's conditioning effect in the critical area.

The plug's thermo-fluid dynamic function must maximize heat extraction from the casting as it solidifies during the die-casting production cycle and also consider the production rate of the system that determines the quantity and potency of the thermal shocks created, which can limit the fatigue strength of the casting.

To achieve the twofold objectives of reducing defects and increasing the life of the insert, we used MAGMA5 software simulations under steady-state thermal conditions to replicate those of actual production (Fig. 3) to support the design of the die.

The simulation of the die-casting process considered all the injection parameters and all phases of the production cycle, perfectly replicating real production. The plug, redesigned to be inserted into the mobile matrix, was studied in four potential configurations with increasingly complex and effective cooling (Fig. 2). The shapes with more or less compact spiral circuits (v03 and v04), take full advantage of the freedom offered by additive printing and provide significantly superior fluid-dynamic performance (Fig. 5) compared to the plugs without cooling (v01) or with only a simple central cooling fountain (v02) that were used as references for suitable correlation.

The comparison considers the water-cooling circuits of the block that operate at an initial temperature of 30°C and a flow rate of 25 litres/minute. This made it possible to identify the greater cooling efficiency achieved by the conformal cooling compared to traditional technology and drastically reduces the thermal shock to the block thereby guaranteeing greater production longevity.

The fluid dynamics analysis conducted on the circuit verified the superior performance in terms of temperature, speed, and heat exchange (HTC) (Fig. 4). Both the parameters used, and the geometric shape of the circuit guarantee remarkable stability and constancy throughout the flow circuit. Most importantly, the analysis verified that the thermal degradation between the inlet (30°C) and the outlet (30.1°C) is practically zero, indicating maximum efficiency. This result was ensured by the high flow velocity of the cooling fluid within the circuit and as expected, heat exchange (HTC) is particularly high throughout the circuit, ensuring the plug's remarkably effective temperature regulation.

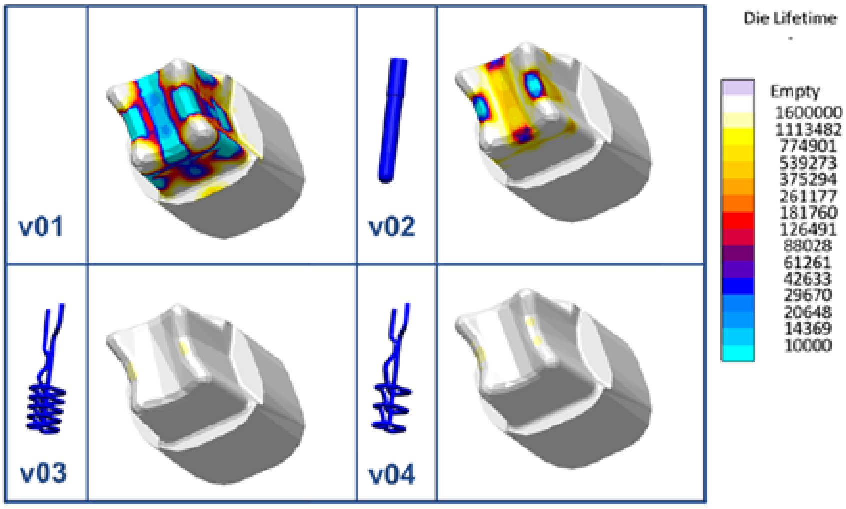

Fig. 2. Study of special thermoregulation system using MAGMASOFT.

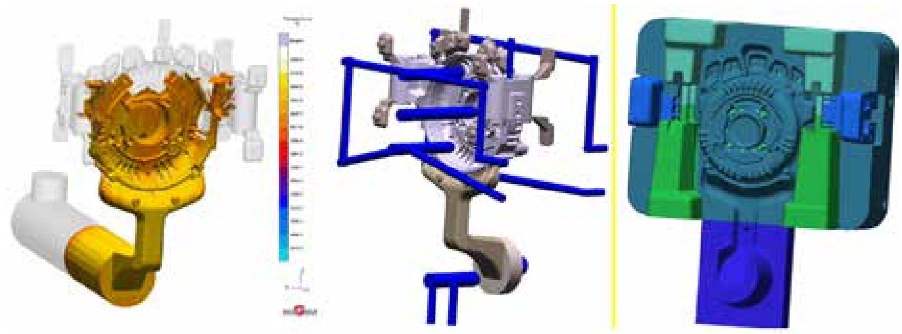

Fig. 3. Simulation of the thermal process.

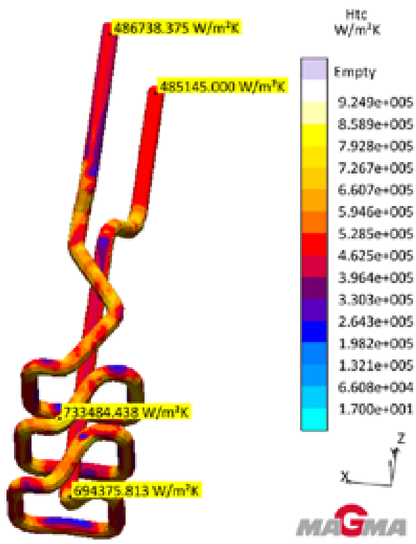

Fig. 4. Fluid dynamics study in terms of heat exchange.

A plug with conformal cooling circuits and large coils (Fig. 4), was finally selected for production using additive technology; this geometric shape also facilitates the production of the insert itself and powder removal after 3D printing. The chosen configuration was finally verified in detail by simulating the thermal conditions during cyclical repetition of the filling and solidification phases of casting. The analysis of the filling and solidification dynamics highlighted the potential formation of residual porosities from air entrapment and shrinkage, particularly in the massive lateral parts of the component (Fig. 5). Fig. 5 shows the distribution of air envelopes (blue) and shrinkage porosities (red) in the right-hand area of the casting. A comparison of this analysis with an analysis of the actual quality using X-ray analysis and destructive testing highlighted the effective correspondence of the defects. This suggested that the shape of the casting should be modified to obtain a completely soundness casting.

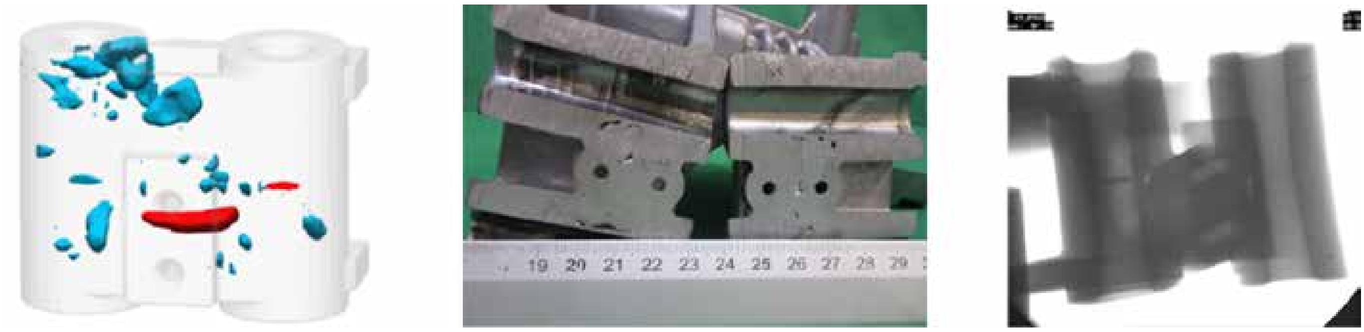

Fig. 5. Detail of predicted porosity defects due to shrinkage and air entrapment compared with X-ray analysis and destructive testing.

The thermal analysis of the plug also confirmed the minimal temperature difference (less than 60°C) before and after the lubrication phase, which guarantees a much longer thermal fatigue life (Fig. 6) than the current 150,000 cycles - an estimated increase of 120%. Lastly, the simulation also revealed a potential reduction in the cycle time thanks to the shorter solidification times of the massive area around the insert.

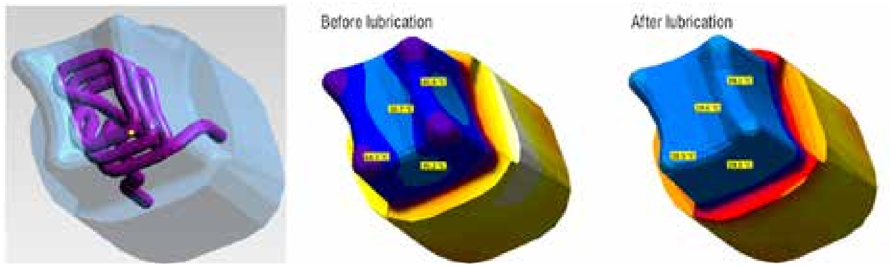

Fig. 6. Thermal analysis of the plug surface.

Simulation of the additive manufacturing process

The creation of dies or parts thereof using additive technology is nothing new; there are numerous applications for plastic injection moulds, and these have also emerged in die-casting and over the last ten years [1-5].

Additive printing of metal alloys is undoubtedly an agile and effective solution for quickly obtaining a plug of the desired shape for better heat removal thanks to the shaped circuits. Obviously each plug, like the one in the case in question, must be made with machines, powders, and process parameters that have been appropriately calibrated and configured to produce a plug of the required density, shape, and size.

The simulation of the AM process made it possible to calibrate the material model based on printing tests and simulation of ad-hoc samples, suited to applications in hot working equipment, and to study the orientation and the supports necessary for 3D printing in order to obtain a high-quality moulded insert at the first attempt. Like the simulation of the die-casting process, the simulation of the L-PBF 3D printing process also aims to numerically solve all the processes and metallurgical phenomena that occur during the laser sintering of the metal material deposited in powder form.

The targeted fusion determines the melt pool and the sequence of the deposited layers, while the path of the laser affects the size of the different melt pools that overlap and cool rapidly. A thermomechanical analysis follows the evolution from liquid to solid to predict the stresses and deformations generated at each layer and consequently within the final as-built state. The orientation and print layout, like all machine parameters, are inputs to the simulation which aims to virtually investigate the ideal setup required to obtain a complete and dimensionally correct part for the post-processing phase. The cross-section and layout of the shaped channels designed to maximize the fluid dynamic efficiency for cooling the plug must be self-supporting during printing to avoid the use of supports inside the channels and to ensure that any residual non-sintered powder can easily be removed.

Even though the insert in this study is compact and the ideal orientation for its printing is well known, all possible orientations were studied. These simulations provided useful results regarding the stability of the channels and the optimization of the printing parameters for the H13 material.

Calibrating the material model

Since the temperature-dependent thermo-mechanical properties of the H13 material were not available (because the temperature varies), it was decided to use an elastic-plastic material model with the same mechanical properties as this type of steel so that an inherent strain simulation could be performed. This method allows the powder bed additive process simulation to be performed as a purely mechanical (structural) simulation based on the base material's mechanical properties in as-built conditions, and on a calibrated material model of the intrinsic characteristic deformation (inherent strain) deriving from the nature of the process itself and from the setup used (hardware, process parameters, scanning strategy, etc.).

To determine the inherent strain value, most commercial software requires the user to print calibration specimens designed to distort significantly, such as a cantilever of the type shown in Fig. 8 which facilitate distortion measurements. The first activity therefore consisted of creating the material model containing the physical and mechanical properties of the alloy in its as-built condition, i.e. after printing.

These properties (listed below) were found in the literature and converted into true values

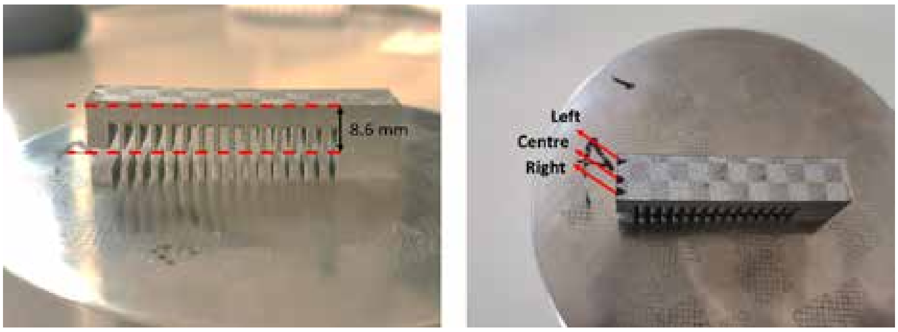

Fig. 7. Cantilever beam after being partially cut from platform (source: UNIPD_DII).

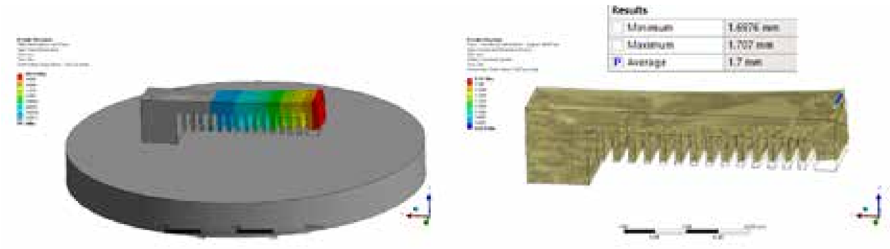

Fig. 8. Z-directional strain of the specimen and calibration of the SSF coefficient.

(true stress, true strain) to create the material model in Ansys Workbench:

- density, $\rho = 7800 kg/m^3$,
- elastic modulus, $E = 215 GPa$,
- poisson's ratio, $\nu = 0.3$,
- yield strength $\sigma_y = 1512 MPa$,
- tensile strength $\sigma_u = 1894 MPa$,
- maximum elongation of 10% (0.1mm/mm).

The calibration procedure involves the creation of specimens (cantilever beams) using the standard scanning strategy that will then be used for the creation of the product. In order to improve the statistical analysis and limit the influence of manufacturing defects it was decided to make several specimens of which at least three were investigated. Once the specimens were made, they had to be partially cut from the platform while leaving intact the thicker section of the tack connecting them to the platform (Fig. 8). The measurement of the Z-dimension at the upper end of the bar tack is used for calibration by comparing it with the simulation values.

Calibration using the measured experimental results is achieved by repeating the simulations and adjusting the calibration factor (Strain Scaling Factor – SSF) to achieve convergence with an acceptable level of error between the measured and simulated distortions at a value of 1.7mm (Fig. 7). This procedure was performed using two products in the Ansys Additive suite, namely Ansys Workbench Additive with an optimal SSF of 0.41005, and Ansys Additive Print with a calibrated SSF of 0.434.

Print simulation of insert

Once the material model is calibrated, the additive process simulation verifies the quality of the virtual prototype using the already optimized printing parameters (Table 1).
The simulation was performed by discretizing the insert in tetrahedral finite elements with an intermediate node (quadratic formulation), which provides a good representation of the geometric features of the component and facilitates the next steps of post-processing and analysis of the results (distortions and residual deformations/tensions). The supports, on the other hand, are made homogenous using linear hexahedral finite elements. The actual amount of material contained in each one is considered by means of a knockdown factor for the mechanical properties. The discretization is obviously a layered mesh, in the sense that the geometry is subdivided into layers of finite elements, in this case all having the same thickness of 0.4mm. Considering that the actual component will be moulded in 20μm layers, this means that 20 layers of cast material are packed into one layer of finite elements.

The results of the preliminary simulations performed with Ansys Additive Print are shown below in terms of distortions, or rather, displacements (relative) to the simulated nominal (the blank), as well as other significant quantities depending on the magnitude. All results are in the as-built condition immediately after printing with the part still joined to the platform. Optical scanning and CT analysis of the as-built plug confirmed the predictions produced by the simulation with Ansys Additive suite.

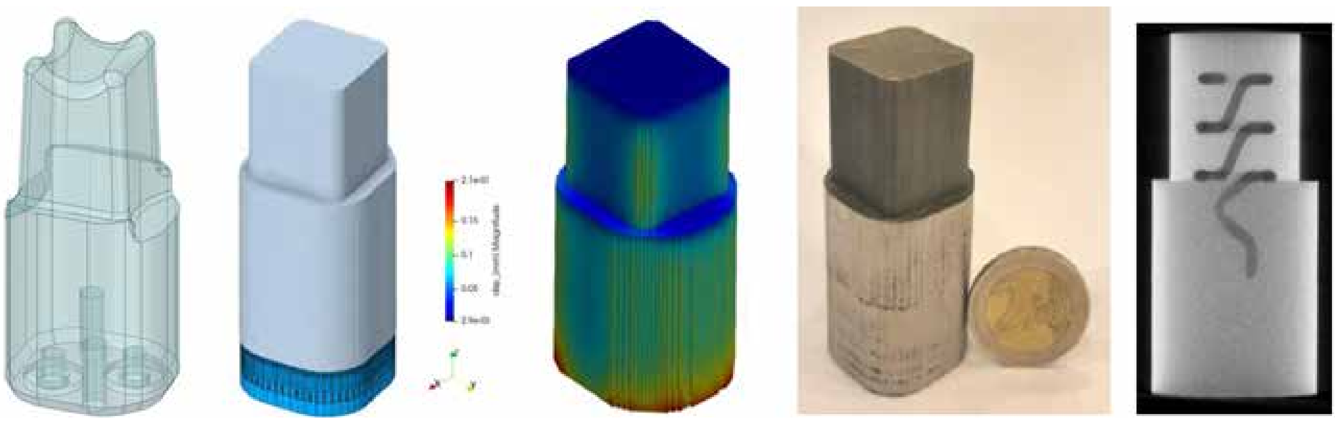

Fig. 9. Comparison of the blank of the insert and the print simulation (left). Insert manufactured using L-PBF parameters optimized by means of a preliminary experimental campaign and CT check of the moulded block (right).

3D-printing of the die insert

The steel powders for the H13 moulds were produced by Hogonas and supplied by MBN Nanomaterialia. The distribution of particles is shown in Table 1, following sieving after delivery, i.e. the dimensions of all the particles below 10%, 50% and 90% are indicated. The apparent density is 4.38g/cm^3, and the density measured with a pycnometer is 7.73g/cm^3.

	Delivered State	After Sieving
d10	33.3μm	29.6μm
d50	45.5μm	38.5μm
d90	62.0μm	50.0μm

Table 1. Distribution of H13 powder particles in the delivered state and after sieving

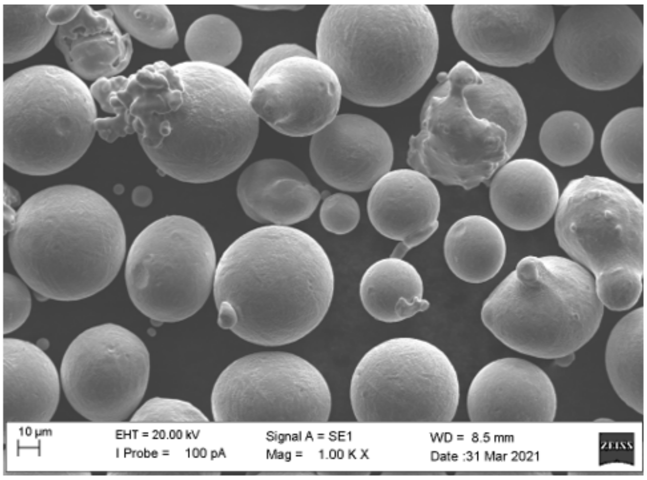

Fig. 10. SEM image of H13 powder after sieving.

Fig. 10 shows a scanning electron microscope (SEM) image of the powder particles after sieving: they have a rounded shape and sufficiently homogenous distribution to be suitable for the laser powder bed fusion (L-PBF) additive manufacturing process.

The L-PBF machine used to make the inserts is a Sisma MYSINT100 3D printer in the University of Padua's processing technologies and systems laboratory in the Department of Industrial Engineering (DII). This machine is equipped with a laser that has a 30μm spot diameter and a maximum power of 200W. Printing takes place in an argon-injected inert atmosphere to guarantee an oxygen content of less than 0.1%, thereby preventing oxidation of the powders.

An extensive experimental campaign (50 experiments) was conducted using a Design of Experiments (DoE) method to identify the optimal set of L-BPF process parameters. The layer thickness was kept constant at 0.02mm as was the laser spot at 30μm, while the laser power, scanning speed, and hatch spacing were varied as shown in Table 2. The output parameters chosen were surface roughness and density. Cubes with sides of 50mm were printed, an example of which is shown in Fig. 11.

The density of the printed samples was assessed according to Archimedes' method, favoured due to its simplicity, speed, and cost-

Laser power (W)	70->140
Scanning speed (mm/s)	300 -> 1000
Distance between tracks (mm)	0.05 -> 0.09

Table 2. L-PBF DoE plan

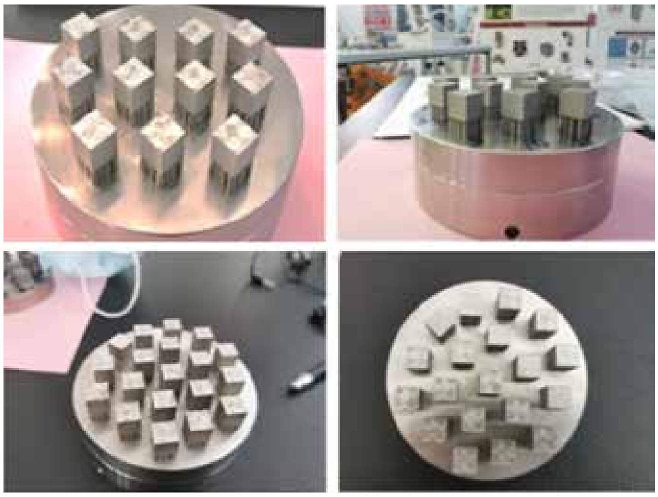

Fig. 11. Examples of samples printed using different L-PBF process parameters.

effectiveness, using a KERN ABT 1205DM scale with a measurement accuracy of 0.01μg. The surface roughness of the samples was measured using the Sensofar SNeox 3D optical profilometer. Given the high roughness of the samples, measurements were performed in focus variation mode using a 20x confocal lens. For each sample, a surface topography with an area of 3.68 x 3.2mm^2 was obtained for both the upper and lateral surfaces. Following the removal of the mould, the surface roughness (Sa) was assessed using ISO 4288.

A relative density of approximately 99.5% and minimal surface roughness on both evaluation surfaces was ensured by the following process parameters:

- laser power = 130W
- scanning speed = 600mm/s
- distance between traces = 0.08mm

These parameters were then used to produce the insert shown in Fig. 9. Following the 3D printing process, the heat treatment shown in Fig. 12 was used to obtain a comparable microstructure and hardness to that of conventionally manufactured H13 steel.

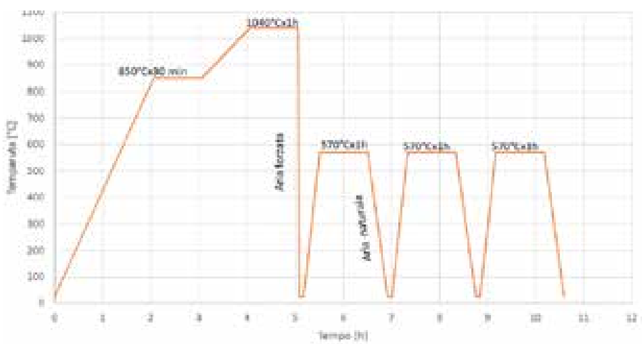

Fig. 12. Heat treatment after the L-PBF process.

This treatment achieved a hardness that was only 5% lower at room temperature than that of conventional H13, and this difference was also maintained at 300°C, thus demonstrating that an optimized L-PBF process combined with heat treatment is able to achieve characteristics similar to those of traditionally produced steel.

Implementation and testing of 3D-printed insert

Machining was performed with no problems and a surface finish comparable to traditionally manufactured and machined steel components was obtained (Fig. 13).

The machining and cutting parameters remained unchanged, enabling the final geometry to be produced promptly. No anomalous behaviour was detected at dimensional level either, as evidenced by the metrological checks performed.

Use of the plug during experimental foundry testing confirmed the efficiency of the thermoregulation system as well as the component's excellent thermal fatigue behaviour: no abnormal or early wear was found.

Analysis was conducted on the die-cast castings and on the pilot mould (a mould created for making die-cast prototypes), using CT scans and comparisons with the results obtained with traditional technologies for the former, and using thermal imaging cameras to monitor temperature trends in the plug area for the latter case.

In conclusion, additive manufacturing enables optimized and perfectly localized thermoregulation geometries to be designed, free of the limitations of traditional manufacturing technologies. This allows the best possible metallurgical results to be achieved for a predefined casting geometry that cannot be further optimized.

Conclusions

The AGILE Project [6-7] emerged from discussions among a group of companies and research organizations based in the Veneto region in the post-pandemic-emergency period and aims to improve the region's industry's ability to convert their production systems in an "agile" manner using advanced solutions for product innovation.

The project falls under the Veneto region's "Smart Manufacturing" specialization strategy within the broader context of business competitiveness for Industry4.0 and represents an organized "industrial reaction" to the Covid-19 emergency characterized by flexibility, reconversion, and resilience.

More specifically, the project develops agile manufacturing solutions and tools to increase competitiveness and product innovation by targeting four areas of development:

- virtualization of the design phase,
- development and industrialization of advanced and high-speed production technologies,
- rapid reconfiguration and optimization of production lines, and
- intelligent quality management.

Fig. 13. Completed plug after machining.

The AGILE Project focuses on specific, representative types of production lines in the Veneto region, and this paper describes the results achieved in High Pressure Die-Casting (HPDC).

Blending two technologies, die-casting, and additive manufacturing, made it simpler and easier to flexibly adjust and improve die performance and casting quality. The virtual design provided useful guidance for optimizing the shape of the thermoregulation circuits of the plug, which was then virtually inserted into the mould to predict its thermo-fluid-dynamic behaviour under thermal conditions typical of HPDC production. Likewise, the simulation of the 3D printing process ensured the highest quality of the 3D printed plugs from the very first print, after which they were machined and inserted into the die for the final test in production.

The MAGMA simulation software allowed the qualitative impact of different thermoregulation configurations on the die-casting process to be quickly compared, while the simulation of the AM technology with Ansys Additive suite enabled the designer to freely create the geometry that would yield the best results.

The technological development of 3D printing systems and the ability to use base powders made of the same materials as those used for traditional production of die-casting moulds provides the following benefits:

- Reduced die-casting costs in terms of materials and machining;
- Shorter lead times for manufacturing of components due to the use of AM;
- Consistent implementation of the best thermoregulation according to the customer's requirements and on the basis of numerical simulation findings;
- Decreased cycle times resulting in lower costs and increased competitiveness;

- Reduced scrap due to the improved casting quality;
- Lower energy consumption thanks to the reduced cycle times, fewer scrap castings and therefore less need to recycle them.

Acknowledgements

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For more information:

Nicola Gramegna - EnginSoft
n.gramegna@enginsoft.com

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Additive Manufacturing

References

[1] J. K. Pancholi, B. Padhiyar, V. Sutariya, and H. Pancholi, "Design and Analysis of Die Casting Die with Conformal Cooling Channel", *International Journal of Engineering Science and Computing,* March 2019

[2] L. Shu, Z. Zhang, Z. Ren, and T. Zhang, "Design and simulation of conformal cooling for a die-casting mold insert", *Journal of Physics:* Conference Series 1939 (2021)

[3] G. S. Phull, S. Kumar, R. S. Walia, "Conformal Cooling for Molds produced by Additive Manufacturing: a review", *International Journal of Mechanical Engineering and Technology* (IJMET) 9: 1, January 2018, pp. 1162–1172, Article ID: IJMET_09_01_124

[4] M. S. Shinde, and K. M. Ashtankar, "Additive manufacturing–assisted conformal cooling channels in mold manufacturing processes", *Advances in Mechanical Engineering* Vol. 9(5) 1–14, 2017

[5] P. Cicconi, M. Mandolini, F. Santucci, and M. Germani, "Designing die insert by additive approach: a test case", 31st CIRP Design Conference 2021 (CIRP Design 2021)

[6] N. Gramegna, and F. Bonollo, "Challenges and Benefits in AGILE manufacturing applied to metalworking production processes", 39° Convegno Nazionale AIM, September 2022, Padua, Italy

[7] Gramegna, N., Greggio, F., Bonollo, "Smart Factory Competitiveness Based on Real Time Monitoring and Quality Predictive Model Applied to Multi-stages Production Lines", in B. Lalic et al (eds) *Advances in Production Management Systems. Towards Smart and Digital Manufacturing,* APMS 2020. IFIP Advances in Information and Communication Technology, vol 592. Springer, Cham. doi.org/10.1007/978-3-030-57997-5_22

AIM's Powder Metallurgy and Additive Technologies Centre

ASSOCIAZIONE ITALIANA DI METALLURGIA

AIM (Associazione Italiana di Metallurgia) is the technical-scientific association of reference for the Italian national metalworking industry. It was founded in 1946 for knowledge diffusion and to increase the use of metallic and other materials in engineering. Through its activities the association aims to promote the exchange of ideas and experiences between all those interested developing and deepening knowledge about metallic materials, and particularly between producers, processors, users and researchers as members of the supply chain.

One of its first committees was the Powder Metallurgy Centre, established in 1959, which aims to create a bridge between the academic world and the various industrial players in the metal powder production chain. Since its inception, the Centre has actively disseminated knowledge on the production, use, and processing of metal powders, and has promoted applications for sintered materials. Through its authoritative and prominent members, the committee has been able to record and contribute to developments in the various sectors preparing sintered products. These include developments in the quality and available types of powders, increases and improvements in press productivity and the development of new models such as electric presses, as well as consolidating the reliability of sintering plants and final treatments. These activities have increased the diffusion of sintered parts in industry and have promoted an increasingly strong cultural and technical awareness of the potential in re-designing certain parts previously produced with so-called traditional technologies. At the same time, the increased use has incentivized ongoing study and development of new, increasingly high-performance solutions.

Italian industry has always held a prominent position internationally and consequently committee members have always focused on the internationalization of the contributions aimed at developing Italian manufacturing in an increasingly borderless context. Accordingly, events organized in the 60-plus years of the Centre's existence have featured European speakers and likewise committee members have presented in international arenas. Over the years, new technologies have been developed and added to traditional pressing and sintering in furnaces, namely the MIM process (since the early 1980s), plasma sintering (2000s), and more recently the family of additive technologies. It is the latter group that has increasingly attracted the attention of the scientific and industrial community due to its undoubted ability to propose highly innovative solutions in multiple fields. The committee, therefore, being sensitive to technological innovations and changes, adopted the name Powder Metallurgy and Additive Technologies in 2017. The new name of the committee clearly reflects the spirit of its members who believe strongly in the value of traditional technologies, in the importance of innovating in even well-established processes, and simultaneously in disseminating technical-metallurgical knowledge in new areas in order to increase skills and actively attract new players.

The committee offers numerous training and refresher courses dedicated to Additive Manufacturing amongst which the six-monthly Additive Metallurgy Course is very popular. The complete list of activities and publications is available at: aimnet.it

Advancements in neuroprosthetics: the SYNCH Project

by Giovanni Falcitelli
EnginSoft

The SYNCH (SYnaptically connected brain-silicon Neural Closed-loop Hybrid system) Project is a European research project under the Horizon 2020 Future and Emerging Technologies Programme. This innovative effort aims to create a hybrid system in which a neural network in the brain of a living animal interacts with a silicon neural network of spiking neurons via neuromorphic synapses. The goal of the project is to establish a synapse-inspired reciprocal link between these networks and use the silicon neural network as a processing architecture to adaptively stimulate and rescue functionality in an animal model of disease.

The SYNCH Project concept

The SYNCH project envisions an invasive brain-computer interface in which brain-inspired processing replaces standard PC-based computation. The interaction occurs between a biological neural network (BNN) and a silicon neural network (SNN). This concept encompasses many levels of complexity since the brain-inspired processing takes place in separate neuromorphic devices:

- The neural interface (NIF) is the physical prothesis in direct contact with the neural tissue.
- The memristor array (MA) or memory resistors manage synaptic-like processing, linking artificial and biological neurons by emulating synaptic integration and plasticity.
- The CU (control unit) is intended to be versatile and enable the acquisition and generation of analogue/mixed signals, pre-processing, and routing of signals between the BNN and the artificial SNN neural networks.

Memristors in neuroprosthetics

Memristors are noteworthy for their future potential in neuroprosthetics. SYNCH uses a memristor array as a platform to perform analogue or mixed digital-analogue processing of neural signals by implementing algorithms inspired by the way biological synapses process spikes. The MA works synergistically with the CU, acting as a neuromorphic processor in response to signals from the BNN and SNN. Together,

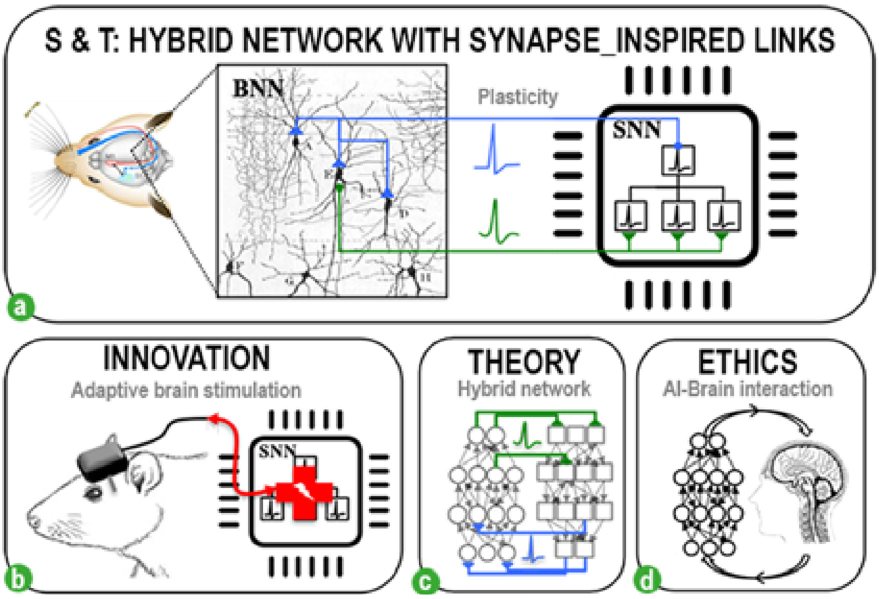

Fig. 1. Star-shaped topology of the locally integrated SYNCH network, with the CU at its centre.

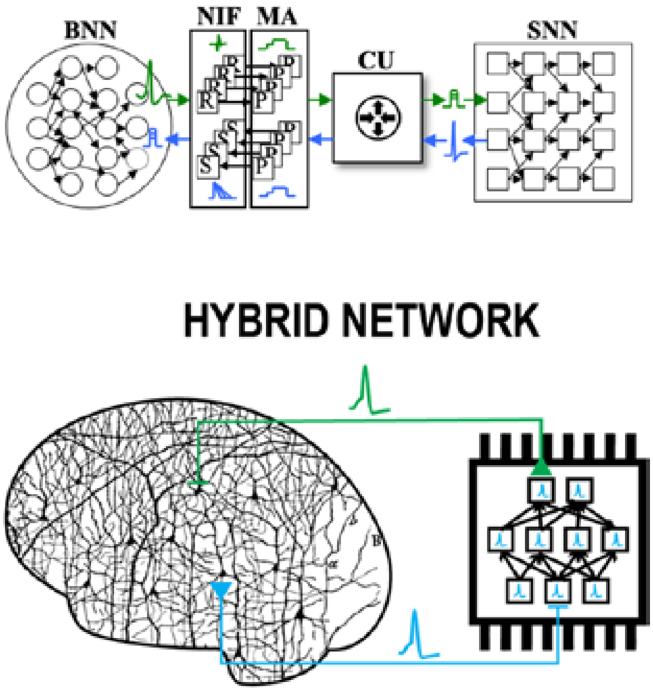

Fig. 2. SYNCH system diagram showing the NIF (neural interface); MA (memristor array platform); CU (control unit); BNN (biological neural network); and SNN (silicon neural network). In our context, the BNN is a biological network in a rat's brain (the somatosensory cortex of an anaesthetized animal at UNIPD, and the basal ganglia of a free-behaving animal at BIU), while the SNN is DynapSE hardware provided by SYNSENSE. The MA is controlled by an ARC board (SOTON and ARC).

they could be used in future implants designed to rescue simple reflex-based circuits located in the integration centres of the spinal cord or brainstem. This could potentially be beneficial in treating autonomic nervous system dysfunctions.

A higher level of processing occurs in the SNN, where brain-inspired computation relies on neuronal network dynamics. The SNN, alone or in combination with memristor arrays, could form part of neuroprostheses to treat focal pathologies in higher brain structures, such as the cortex (in epilepsy or stroke), or the basal ganglia (in Parkinson's disease).

EnginSoft's role in the SYNCH Project

EnginSoft is one of the partners in the SYNCH Project and is contributing by using finite element method (FEM) techniques to model the micro capacitive needles that predict electrical behaviour post-implantation. The NeuroChip laboratory of the Padua Neuroscience Centre (PNC) commissioned EnginSoft to develop a full parametric FE model of a microelectrode array, a crucial component for improving neurostimulation implants.

The microelectrode array developed by EnginSoft is an assembly of ten units, each equipped with one stimulation plate and several sensing microelectrodes. The design integrated three innovative elements:

- The stimulation plate and the electrodes are electrically insulated from each other. This separation physically isolates the channels for signals stimulating the neural tissue from the signals from the neurons.
- The transmission of electrical signals occurs by capacitance rather than by conductivity.
- Titanium dioxide (TiO_2) was used for the microelectrodes instead of iridium oxide (IrO), the standard material.

EnginSoft used Ansys Electronic Desktop to create the challenging parametric FE model of the capacitive needle containing all microelectrodes immersed in a conductive dielectric with properties similar to neural tissue. The software was chosen for its ability to build robust parametric geometries from scratch, the auto-adaptive meshing strategy, high-performance computing solvers, powerful post-processing tools, and automated routines to calculate the capacitance and the conductance matrices.

SYNCH Project progress

The SYNCH project has made significant progress since it started in 2019. It has seen effective cooperation between the different partners, all of whom have made remarkable progress in their respective fields, contributing towards the overall success of the project. A brief summary of the progress made by each of the partners follows:

- EnginSoft successfully designed a full parametric FE model of a microelectrode array that is now capable of predicting the array's electrical behaviour after implantation.
- Padua Neuroscience Centre's NeuroChip laboratory has reached significant milestones in improving neurostimulation implants.
- Memristors have successfully been used to link artificial and biological neurons thereby achieving the project's objective of creating a hybrid system.
- EnginSoft's implementation of FEM techniques has proved instrumental in advancing the project.
- EnginSoft's development of a microelectrode array represented a significant milestone for the project.

EnginSoft's successes in the SYNCH Project

EnginSoft's dedication to the project has led to the successful development of a full parametric FE model of a microelectrode array. This represents a crucial step in improving neurostimulation implants. The company's work in the SYNCH project demonstrates its commitment to the advancement of neuroprosthetics and its ability to effectively collaborate in multi-disciplinary research projects.

Conclusion

The SYNCH project represents a significant stride forward in the field of neuroprosthetics. The advancements that have been made in the project are not only ground-breaking in neuroprosthetics but also highlight the power of effective collaboration in multi-disciplinary research endeavours.

For further information, visit: synch.eucoord2020.com
Or contact: Stefano Vassanelli - University of Padova
stefano.vassanelli@unipd.it

Calculating the Coriolis mass for a blow-torched shell resonator simulated with Ansys

by Jun Young Jeong
TAE SUNG S&E

In this article, a shell resonator refers to a three-dimensional shape, such as a hemisphere [1] or a half-toroid [2∼4], designed to mitigate energy loss due to vibrations. This type of resonator has several vibration modes such as up-down, tilting, wine-glass mode, etc. Wine-glass mode refers to a deformation of the rim of a resonator where the circumference of the rim is a natural multiple of two or more; it is a multiple of the mode wavelength.

Since wine-glass vibrations in a non-inertial system undergo precession through rotation due to the Coriolis effect, the rotation or speed of rotation of the system can be detected from the angle of precession. Therefore, the shell resonator is a key component of a Coriolis vibrating gyroscope (CVG), a device that measures rotation or rotational speed.

Shell resonators design should reduce energy losses because the higher the quality factor and angular gain, the better the performance of a gyroscope. The quality factor reflects the duration of the resonator's oscillations, and the angular gain, which is the ratio of the effective mass to the Coriolis mass, reflects the rate of precession of the rotating resonator.

More than one million shell resonators are produced using blow-torching and glass-blowing technologies [2∼4]. In this paper we introduce a method to simulate glass forming with blow-torching and glass-blowing using Ansys Polyflow, and calculate the angular gain of a glass-shell resonator using Ansys modal analysis.

Glass-forming simulation using Ansys Polyflow

Glass moulding is a technique that deforms glass by applying pressure when the glass has reached approximately 1,500°C, the temperature at which molten silica softens. Fig. 1 illustrates the concept of the glass-forming experiment to manufacture the shell resonator and the simulation strategy for Ansys Polyflow. Any heat source such as the flame of a gas torch, hot air, or laser beam can be used if they can sufficiently heat the glass substrate. The fused silica substrate is placed over a graphite mould and a heat source heats the substrate. Once the temperature of the substrate approaches its softening temperature of 1,500°C, a vacuum pump is used to decrease the pressure between the substrate and the mould. In the experiment, the pressure difference deforms the substrate into a three-dimensional structure. The flame is removed after a few seconds. The final shape of the 3D structure is determined by:

- thermal energy,
- spatial distribution of the heat source,
- substrate thickness,
- pressure difference,
- duration of deformation,
- mould temperature,
- heat transfer from the substrate to the mould,
- mould structure, etc.

The model in Fig. 1(b) was created with Ansys Polyflow to predict dependencies. The model consists of two parts: a thin substrate and a mould. Each boundary is selected as

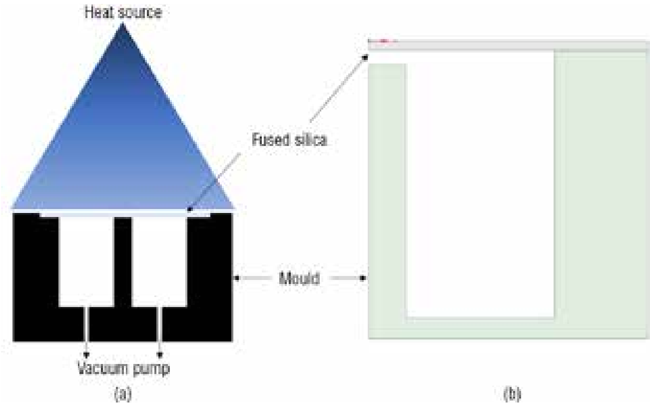

Fig. 1. (a) Experimental concept for blow-torching (b) Model for blow-torching.

Name	Glass Boundary	Name	Mould Boundary
Glass_symmetric	Left side	Mould_contact	Inside
Glass_heat_impose	Top	Mould_symmetric	Left side
Glass_contact	Bottom	Mould_fixed	Right side and bottom
Glass_fixed	Right side	-	-

Table 1. Boundary selection

shown in Table 1, taking into account the Polyflow analysis. It is not necessary for the mesh of the fixed frame to be very fine, but given that deformed substrate is very thin, the substrate mesh must be sufficiently dense. New post-mesh FEM (finite element method) operations are created with 2D axisymmetric geometries in Ansys Polyflow for time dependent problems. Then the subsequent steps follow.

Mould definition

We created a new mould with a constant and uniform temperature and set up the domain. The mould_contact boundary was selected as the contact condition; no fixed mould movement is permitted.

Sub-model: material data

A sub-model for generalized Newtonian non-isothermal flow problems was created for the glass deformation. The sub-task's domain was set for glass, and the material data was set as shown in Table 2. The viscosity of the glass depends on temperature, and Ansys Polyflow has several options for the temperature dependency of viscosity. We used Fulcher's logarithmic law to simulate the glass viscosity [5].

Material data	Value
Viscosity shear-rate dependency	1
Viscosity temperature dependency	Fulcher dependence, $10^{-5.894+\frac{21340.8}{T-239.5}}$
Density (kg/m³)	2,200
Inertial conditions	Taken into account
Coefficient of thermal expansion (1/K)	0.55e-6
Thermal conductivity (W/m·K)	1.4
Thermal capacity per unit mass (J/kg·K)	760

Table 2. Material data for glass

Sub-model: flow boundary condition

The flow boundary conditions were set as shown in Table 3. The upper surface of the glass is the surface in contact with the heat source and normal force was applied due to the pressure difference. The bottom of the glass is the surface in contact with the mould and there was heat transfer from the hot glass to the cold mould.

Boundary of glass	Flow condition
Top	Free surface - Normal force: Negative constant value - No tangential force imposed
Bottom	Free surface - Contact: Along mould-contact boundary with constant alpha and mould temperature
Left side	Axis of symmetry
Right side	Zero wall velocity

Table 3. Flow boundary conditions

A constant rate of heat transfer, alpha, and the mould temperature were adjusted by comparing simulation results with a manufactured resonator. The penetration accuracy was adjusted to prevent numerical errors such as when glass elements penetrate the mould at the contact surface during deformation. The slipping coefficient was set considering that molten silica rarely slips along the mould wall during deformation.

Sub-model: thermal boundary condition

We set the thermal boundary condition according to the values in Table 4. In real experiments, the heat source usually has a spatially Gaussian profile and in actual systems, heat is dissipated from the hot glass into the air. Flow imposition was used instead of temperature imposition as a Gaussian profile can be easily applied.

Boundary of glass	Thermal condition
Top	Flux density imposed, $q = q_c + \alpha[T - T_c], \alpha = a\exp[-\left(\frac{x-b}{c}\right)^2]$
Bottom	Insulated boundary/symmetry
Left side	Axis of symmetry
Right side	Insulated boundary/symmetry

Table 4. Thermal boundary conditions

To consider heat dissipation, we chose zero q_c and specific values of α and T_c. These conditions simulate a finite heat source temperature and heat dissipation proportional to the temperature difference. Heat is only applied to the top and conductive heat transfer heats the entire substrate. We ignored radiational heat dissipation in this simulation. By changing the Gaussian heat density parameter, the size, centre position, and total energy of the heat source can be modified. Global remeshing is also activated because the substrate was deformed during the simulation. The results were then compared with the actual deformed substrate to optimize the numerical parameters.

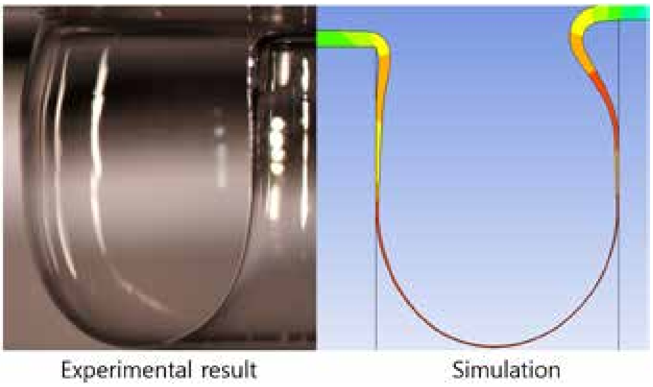

Fig.2. Comparing simulation and experimental results.

Ansys Polyflow results

As mentioned previously, we optimized various parameters, such as the spatial profile of the heat source, the heat transfer rate between the glass and the mould, the mould temperature, etc. to ensure that the results matched the actual deformation.

Fig. 2 shows a blow-torched substrate and the simulation results achieved with Ansys Polyflow. There is good agreement between the simulated geometry and the deformed glass. This model can be used to determine the tendencies of glass formation as an experimental parameter. Furthermore, the results are compatible with other Ansys analyses such as modal analysis. Information on the position of each element and the simulated structure is used in the Ansys modal analysis to analyse the vibration modes and calculate the effective and Coriolis mass.

Mode analysis and calculation of mass parameters

There is no undeformed part in shell resonators, represented by the outer plane in Fig. 2. The unwanted portions of the deformed substrate must therefore be removed. These were split and removed from the Ansys simulation, as shown in Fig. 3, in addition to lapping and polishing. We call this process "trimming".

The simulation results were exported in '.stl' format for further analysis. The deformed substrate geometry was opened and edited in Ansys SpaceClaim. First, the imported geometry was converted into a solid and merged into faces as shown in Fig. 4(a).

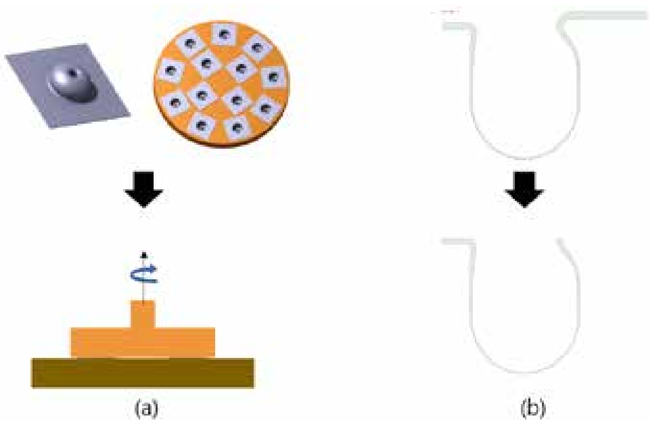

Fig. 3. (a) Removing unwanted parts; (b) Experimental process in simulation.

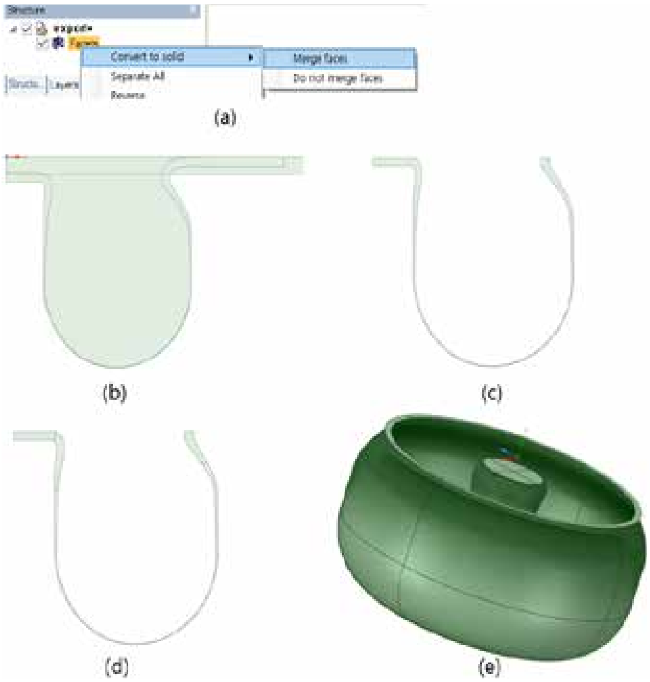

Fig. 4. Trimming and building a 3D structure in SpaceClaim: (a) Convert to solid and merge faces; (b) Sketch a rectangle to make an edge; (c) Remove unwanted parts; (d) Split for efficient meshing; (e) Build a 3D structure by rotating the result of the 2D split.

There are several ways to remove unwanted parts in SpaceClaim. In our case, we sketched a rectangle to create edges, cropped the shape, and removed any unwanted parts.

The two-dimensional result of the trimmed substrate was split into several parts for efficient meshing and rotated to create a 3D geometry like in an actual resonator, as shown in Fig. 4. (d) and (e). The number of parts depends on the overall size and curvature of the shell resonator. We cannot tell which is the best way to divide it, however, one thing is certain: the more parts, the lower the probability of meshing errors occurring.

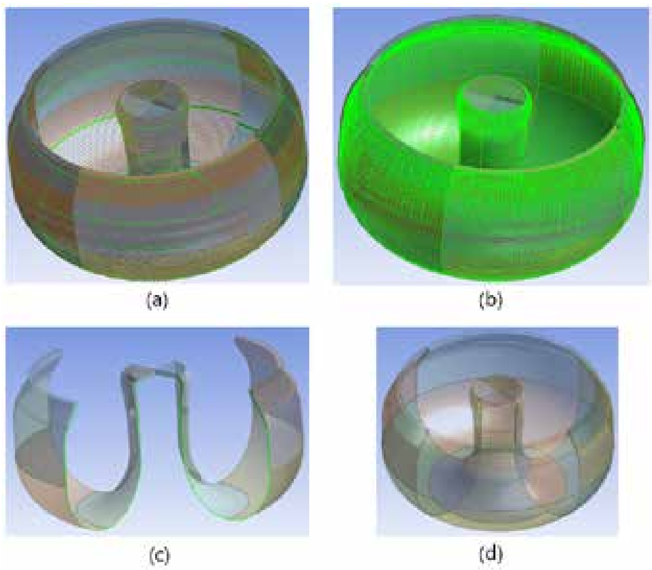

Fig.5. Merging pieces in DesignModeler: (a) Select a surface in each part; (b) Extend the selection and merge the surfaces; (c) Select a single line in each border; (d) Extend the selection and merge the lines.

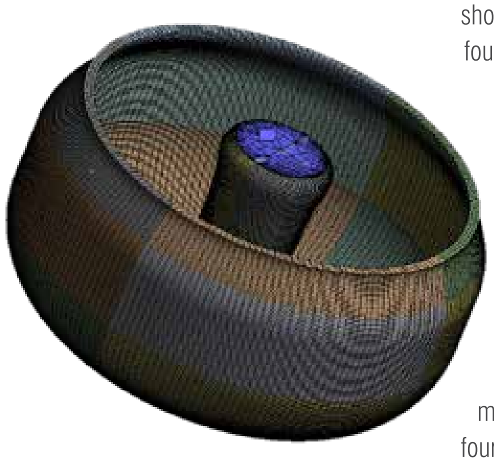

Fig. 6. 3D geometry mesh for modal analysis.

After rotation, the 3D geometry was exported as a parasolid text in the ".x_t" format to be merged into Ansys DesignModeler. Note that the 3D geometry must be shared before exporting. In other words, you must select the "shared" option that can be found in Properties/Analysis/Share Topology.

Although the 3D geometry comes from a single 2D substrate, a single part of the segmented 3D shape consists of several parts, like many pieces of a jigsaw puzzle, as shown in Fig. 5(a). This could be caused by anomalous curvature or by compatibility problems between Polyflow and Space Claim. We wanted each segment of the 3D geometry to consist of a single body, so we combined all the pieces into a single body in DesignModeler by importing the Parasolid text, and created the structure.

During segmentation several parts can be seen, and the 3D geometry is composed of many puzzle pieces as shown in Fig. 5(a). To merge the puzzle pieces into a single body, we selected the entire surface and all borders of the 3D structure, and merged them as shown in (b) and (c). The Merge tool can be found in the Tools menu of DesignModeler. Fig. 5(d) shows the merged 3D geometry. A new part must be formed from the merged parts before the merger can be completed in DesignModeler.

The next step is to use Ansys modal analysis to analyse the vibration mode of the 3D geometry and calculate mathematical masses such as effective mass and Coriolis mass. First, for the fourth step of the modal analysis, we must ensure that the parts have been imported correctly, as sometimes parts are missing or duplicated in the model. If there are no missing or duplicate parts, you can set the materials for the geometry. In our case, the substrate was fused silica, and the Ansys library contains data for fused silica. We then created the mesh.

Some boundary conditions for a successful mesh and the mesh results are shown in Fig. 6. A 3D shape has about 150,000 elements. Of course, the number of elements can be optimized by adjusting the boundary conditions. The bottom surface of the stem in the centre of the 3D geometry is locked in vibration mode, as shown in blue in Fig. 6. Fig. 7 shows the vibration modes that we investigated in Ansys modal analysis. Since the circumference of the rim is twice the wavelength of the vibration, we call this vibration a n=2 wine-glass mode. As can be seen, most of the displacement occurs at the rim and the stem remains almost motionless. Therefore, we can define the effective mass, M_{eff}, the Coriolis mass, M_{cor}, and the angular gain, A_g, as the flux, where ϕ and ρ represent the normalized strain vector and density. The entries of xyz and 1,2 represent the modal exponents for the orthogonal oscillations on the motion axis and n=2 wine-glass oscillations. Here, the Z-axis is parallel to the normal vector of the fixed plane.

$$M_{eff} = \int \rho(\phi_{x1}^2 + \phi_{y1}^2 + \phi_{y1}^2)dV$$

$$M_{Cor} = \int \rho(\phi_{x1}\phi_{y2} - \phi_{x2}\phi_{y1})dV$$

$$A_g = \frac{M_{Cor}}{2M}$$

Angular gain reflects the vibratory response of the wine-glass vibration to rotation. In other words, it is the coefficient of proportionality between the angle of rotation and the angle of precession of the wine-glass vibration. Therefore, we could say that the greater the angular gain, the greater the sensitivity. Ansys provides information on the deformation and volume of each element, even in wine-glass mode.

To calculate the angular gain of a 3D shape, we extract the position and volume of each element at the initial state and the maximum

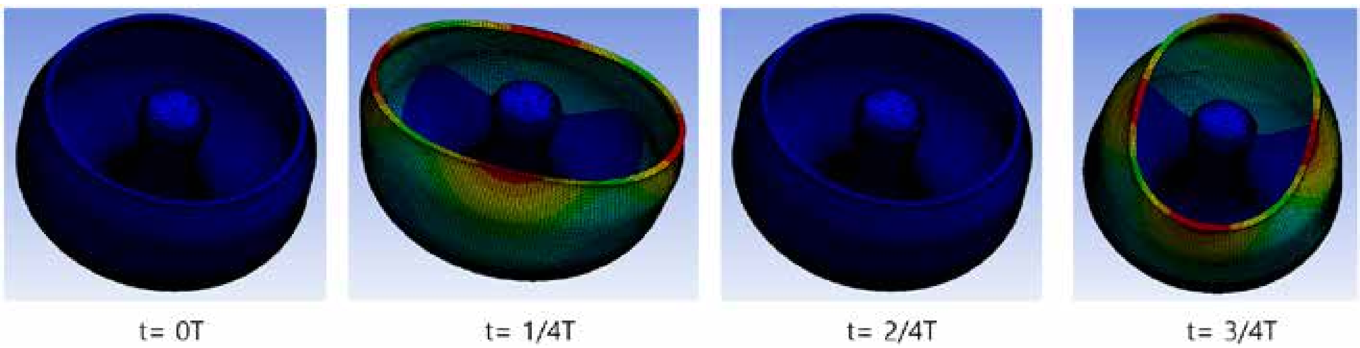

Fig. 7. n=2 wine-glass vibration mode.

Output Controls	
Stress	Yes
Surface Stress	No
Back Stress	No
Strain	Yes
Contact Data	Yes
Nodal Forces	Constrained Nodes
Calculate Reactions	Yes
Store Modal Results	For Future Analysis
General Miscellaneous	Yes
Result File Compression	Program Controlled
Analysis Data Management	
Solver Files Directory	
Future Analysis	MSUP Analyses

Fig. 8. Modal analysis settings for calculating angular gain.

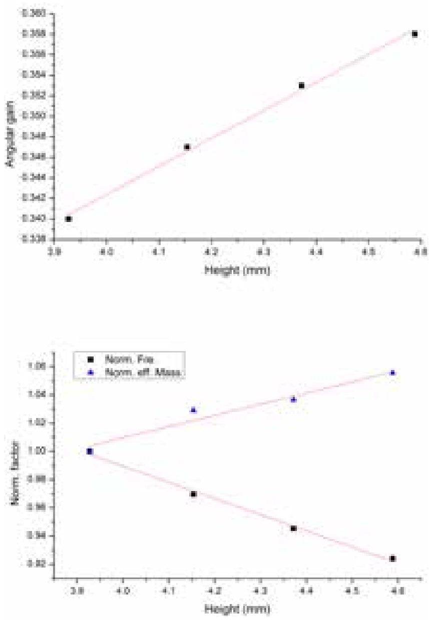

Fig. 9. Results for angular gain, normalized frequency, and effective mass for n=2 wine-glass mode.

deformation state for n=2 modes. The APDL (Ansys parametric design language) command in Ansys allows us to extract information and perform calculations. To extract and store the information, specify the analysis setting in modal, as shown in Fig. 8. For the 3D geometry in this figure, the calculated angular gain is 0.385. The angular gain of the 3D geometry is 0.275 for a hemispherical resonator and 0.2~0.35 for other cases [6, 7].

Fig. 9 shows the calculated angular gain, normalized resonance frequency, and effective mass for the n=2 wine-glass mode as the height of the resonator. In Ansys Polyflow you can change the height at different times. There is good agreement with previous reports [8] for the proportional trend between angular gain and resonator height.

The performance of a gyroscope is limited by a noise floor called ARW (angular random walk) for detection of rotation. ARW for CVG is given by:

$$ARW = \frac{\alpha}{\sqrt{Q}A_g}\sqrt{\left(\frac{\beta\omega_0}{\sqrt{Q}}\right)^2 + \frac{k_B T}{m_{eff}\omega_0}}$$

where Q, A_g, ω_0, k_B, T and m_{eff} are the quality factors, angular gain, resonant frequency, Boltzmann constant, temperature, and effective mass of the resonator [8]; α and β are constants related to the electrical environment and the circuit. Higher Q and angular gain reduce the ARW, which is also a function of effective mass and resonant frequency. From the simulation results, it is possible to estimate the dependency between the geometrical parameters and ARW.

Conclusion

We simulated glass deformation at temperatures above the softening temperature using Ansys Polyflow. Deformation of 2D-modelled axisymmetric geometry were simulated by solving a generalized Newtonian non-isothermal flow problem. We varied parameters such as size of heating source, heating time, energy transfer rate from the glass to the mould, etc. and checked their dependence on these factors.

We transformed the deformed 2D geometries into a 3D structure by rotating them and analysed the vibration characteristics using Ansys modal analysis. The 3D geometry simulated here is used for the CVG shell resonator and the vibration characteristics are key since the ARW of the CVG is limited by resonator properties such as angular gain, effective mass, and resonant frequency and affects quality.

Ansys is a powerful tool that allows us to calculate the resonance frequency, effective mass, and angular gain by extracting each element's position and volume. The APDL commands in Ansys modal analysis perform these extractions and calculations. The results were used to estimate the effect of the experimental parameters and optimize the experimental process. The 3D geometry is used to calculate the quality factors.

References

[1] F. Delhaye, "HRG by Safran – The game-changing technology", 2018 IEEE International Symposium on Inertial Sensors and Systems, Lake Como, Italy, March 27–29, 2018.

[2] J. Cho et al, "0.00016 deg/√hr Angle Random Walk (ARW) and 0.0014 deg/hr Bias Instability (BI) from a 5.2M-Q and 1-cm Precision Shell Integrating (PSI) Gyroscope", 2020 IEEE International Symposium on Inertial Sensors and Systems, virtual format, March 23–26, 2020.

[3] M. Asadian et al, "3D Dual-Shell Micro-Resonators for Harsh Environments", 2020 IEEE International Symposium on Inertial Sensors and Systems, virtual format, March 23–26, 2020.

[4] J. Sun et al, "0.79 ppm scale-factor nonlinearity whole-angle microshell gyroscope realized by real-time calibration of capacitive displacement detection", *Microsystems & Nanoengineering,* vol. 7, pp. 79, 2021.

[5] B. Shiari et al, "Simulation of Blowtorch Reflow of Fused Silica Micro-Shell Resonators", *Journal of Microelectromechanical Systems*, vol. 26, pp. 782, 2017.

[6] W. Zhao et al, "High sensitivity rate-integrating hemispherical resonator gyroscope with dead area compensation for damping asymmetry", *Scientific Reports,* vol. 11, pp. 2195, 2021.

[7] Y. Chen et al, "Simulated analysis of forming imperfection for micro shell resonators", *Microsystem Technologies,* vol. 27, pp. 723, 2021.

[8] A. Darvishian, "Design and Analysis of Extremely Low-Noise MEMS Gyroscopes for Navigation", PhD thesis, Dept. Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI, USA, 2018.

For more information:
Jun Young Jeong, TAE SUNG S&E
jyjeong@tsne.co.kr

About TSNE

Since its establishment in 1988, TSNE has specialized in CAE, providing engineering programs and services to Korean customers. Tae Sung S&E (TSNE) aims to be the "One Stop Total CAE Solution Provider" (OSTS) both in domestic and global markets. The company leverages its large base of business capabilities and its team of CAE experts to provide services to customers in various industries (aerospace, automotive, civil engineering, biomedical, shipbuilding, electrical and electronics, energy, defence, chemical industries, etc.) and is expanding its business scope to research innovative technologies and apply them in the field. It strives to become a global engineering company and increase its potential as a sustainable engineering company. Tae Sung S&E partners all engineers who endeavour to solve challenges. Tae Sung S&E will work with you to achieve "NO PROBLEM, BE HAPPY".

EnginSoft strengthens its presence in Europe by establishing a French subsidiary

EnginSoft has announced the opening of E-SOFT France, its new French subsidiary in Paris.

E-SOFT France will offer the products and services supported by EnginSoft, which are articulated into four complementary areas of intervention focusing on technology transfer. These are consultancy, software products and their integration into customers' design and production processes, training, and applied research. All are activities in which EnginSoft draws fully on its in-house technical skills and those of its network.

Stefano Odorizzi, founder and president of EnginSoft, states: "The opening of the French subsidiary will allow us to be directly present in the second most important market in Europe for our specific offer, and to better serve our existing and future customers." He explains: "EnginSoft has always operated through a network of its own branches and other variously affiliated or associated technical entities. This approach enables us both to best express our expertise in specialised and "vertical" areas, and to guarantee sustainable implementation for customers with organizations of different sizes and in different contexts."

Odorizzi adds: "EnginSoft has forty years of experience in this field, having implemented this approach since the company's earliest days, when the knowledge and technologies were mostly in the domain of universities and researchers. We have always managed to stay ahead of the trends, and have thereby been able to accompany our customers along their individual growth paths, both by keeping an eye on the future, and by being conscious of the nature and amount of work necessary to assist our customers in realizing their objectives."

Patrick Martinez, CEO of E-SOFT France, comments: "I enthusiastically welcomed the opportunity to lead the French subsidiary of EnginSoft. Having come from this industry, I knew EnginSoft as an international group uniquely able to add genuine value to the companies it serves. I have always worked with this spirit, and intend to continue to do so in E-SOFT France. I sincerely believe that the richness and efficiency of EnginSoft's strongly cohesive network that allows us to access and deploy all the different expertise required, makes EnginSoft a partner of excellence for companies undergoing the process of digital transformation."

For more information:
www.esoftfrance.fr

Patrick Martinez, CEO of E-SOFT France

Stefano Odorizzi, founder and president of EnginSoft

EnginSoft USA named on the 2023 *Inc. 5000* list with three-year revenue growth

EnginSoft USA ranks among America's fastest-growing private companies

Inc. magazine revealed that EnginSoft USA, a leading computer aided engineering (CAE) company, ranked on the 2023 *Inc. 5000* annual list of the fastest-growing private companies in America.

The prestigious ranking provides a data-driven look at the most successful companies within the economy's most dynamic segment – its independent, entrepreneurial businesses.

"It's a tremendous honour for us to secure a place on the prestigious *Inc. 5000* List of the Fastest Growing Private Companies in America," stated Chris Wilkes, President and CEO of EnginSoft USA. "Our unwavering dedication and passion to assisting our clients has been pivotal in propelling our achievements, as evidenced by the exceptional standard of service and assistance we provide."

The *Inc. 5000* class of 2023 represents companies that have driven rapid revenue growth while navigating inflationary pressure, the rising costs of capital, and seemingly intractable hiring challenges. Among this year's top 500 companies, the average median three-year revenue growth rate ticked up to an astonishing 2.238%. In all, this year's *Inc. 5000* companies have added 1,187,266 jobs to the economy over the past three years.

"We congratulate EnginSoft USA for being recognized on the *Inc. 5000* list," said Brian Thompson, General Manager of Creo at PTC. "As a valued partner to PTC, we wish EnginSoft continued growth and success in the years ahead."

For complete results of the *Inc. 5000*, including company profiles and an interactive database that can be sorted by industry, location, and other criteria, go to inc.com/inc5000. The top 500 companies are featured in the September issue of *Inc.* magazine, which was available on newsstands from Tuesday, August 23.

"Running a business has only got harder since the end of the pandemic," says *Inc.* Editor-in-Chief, Scott Omelianuk. "To make the *Inc. 5000* – with the fast growth that requires – is truly an accomplishment. *Inc.* is thrilled to honour the companies that are building our future."

EnginSoft USA is the leading technology transfer company in the field of CAE. It leverages CAE tools to help customers solve complex product development problems by combining technology transfer with consulting, training, and research. EnginSoft engineers have extensive experience and expertise in multibody dynamics and CFD consulting and have completed thousands of CAE projects across a broad range of industries that include automotive, energy, oil and gas, aerospace and defence, civil and structural engineering, metals, machining and manufacturing, consumer goods and appliances, healthcare and biomechanics, helping customers to leverage existing legacy and emerging simulation technologies.

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Its proprietary *Inc. 5000* list, produced every year since 1982, analyses company data to rank the fastest-growing privately held businesses in the United States. The recognition that comes with inclusion on this and other prestigious *Inc.* lists, such as *Female Founders* and *Power Partners*, gives the founders of top businesses the opportunity to engage with an exclusive community of their peers, and credibility that helps them drive sales and recruit talent. For more information, visit inc.com.

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