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PILOT RESEARCH & DEVELOPMENT OF A MULTIFUNCTIONAL AND MULTI–PURPOSE SPORTS EQUIPMENT – AUTOMOTIVE TECHNOLOGIES FOR THE OLYMPICS

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Abstract: Teqball, a new football–based sport developed in Hungary, is played on a specially curved table (Teq table). This recently invented sport is a great way for both professional and amateur athletes to improve their technical skills, concentration and endurance. The development of the first versions of the special curved Teq table suitable for mass production and the technologies to produce them started in 2017. At the outset of the development process, there was a clear commitment to create a high–quality product. The manufacturing technologies have therefore been based on the requirements, standards and technologies used in the automotive industry, given the high–quality expectations of the industry. The research & development of the first versions of the Teq tables posed a number of technical challenges: how to apply automotive solutions to sports equipment manufacturing.
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INTRODUCTION

The Teq table is a multifunctional sports equipment similar to a ping–pong table, except that the tabletops are curved instead of flat (Figure 1). Despite the seemingly insignificant difference between the two sports equipment, there are significant differences in the background, both in terms of the design and the manufacturing technology. There are also significant differences in the type of sports played on the sports equipment.

1Figure 1: Teq table

Among the sports that can be played on the Teq tables, Teqball is the basic sport for which the sports equipment must be suitable. For Teqball, a size 5 soccer ball weighing 350–450 grams [1] is used, giving the ball a static load more than 100 times that of a ping–pong ball and an even higher dynamic load.

In Teqball, the main guiding principle in designing the bouncing characteristics of the ball was that it should always bounce towards the player standing behind and/or next to the table for ease of play and continuity of play. This principle provided the basis for developing a curved tabletop shape for the game in the early stages.

The development of the design and manufacturing technology of the Teq table as a sports equipment required a new approach due to the increased load of the game and the curved shape of the tabletop. As the Teq tables are mainly used outdoors due to the larger space requirements, the sports equipment must be able to withstand extreme weather conditions.

In 2017, Teqball Kft., a Hungarian company has set the goal of developing designs suitable for mass production that meet the complex and high requirements, where the appropriate production technology is taken into account during the research and development phase, in addition to the choice of materials.

CONCEPTS, RAW MATERIALS, PRODUCTION TECHNOLOGIES

As a first step in the development project, we analyzed the initial concepts. As a result of the analysis, we have clearly concluded that the concept of Teq tables needs to be completely changed, with new technical solutions in terms of the structural design, material composition and manufacturing technology. During the research, we collected the known requirements that formed the basis for the conceptual design of the project. In developing these concepts, we have set ourselves two main objectives:

- defining and standardizing the dimensions of the Teq tables, and
- creating the design plans.

The conceptual design started with a fixed–design table and selected the three best development directions:

- Version with lattice bracing

For the first version, a lattice–framed structure was created, with lattice–framed stiffening ribs under the tabletops to achieve the required rigidity. In this case, it is not necessary to design and manufacture tabletops with high rigidity, the load bearing is provided by the lattice supports under the tabletops.

- Integrated strut version

For this concept, the bracing ribs are integrated into the structure of the tabletop providing the playing surface. This would allow faster assembly with more compact components.

- Separate tabletop frame and playing surface

The key part of the Teq table is the curved tabletop. Since the tabletops need to be sufficiently rigid but also provide the gaming experience, we developed a concept where the actual playing surface is separated from the structure that provides the rigidity.

Once the concepts were developed, we looked at the possible materials that could meet the requirements.

1Table 1. Main structural units

Material type	Main structural units		
	Foot structure	"Net"	Tabletop
Wood	with appropriate surface treatment	–	with appropriate surface treatment
Structural steel (S235)	with appropriate surface treatment	with appropriate surface treatment	with appropriate surface treatment
Stainless steel	X	X	X
Aluminum alloy	X	X	X
Polymers (PE, PA, PVC, PMMA, PC, etc.)	–	X	–
Composites (laminated)	X	X	X
Composites (pressed)	X	X	X

Following the research, a list of possible materials was compiled. The main criteria for selection were adequate rigidity, corrosion resistance and good formability. Wood materials may be suitable for the leg structure and the tabletop, but surface treatment is required to make them suitable for outdoor use. Wooden materials should not be used for the "net" structural element, as there is a high risk of rapid deterioration due to the cyclical, heavy load ball impact, tiring the structure. Structural steel (S235) is a very good alternative for all structural elements. It has the advantage of being rigid and formable, but due to the outdoor use, corrosion protection is an important aspect. The polymers are well suited to Teq tables in smaller sizes (e.g. the "net" element), but in larger sizes (leg structure and tabletop) rigidity problems can occur. Composite materials would be well suited for all structural elements, as several material compositions can be implemented to provide the required rigidity. [2] They are also very good in terms of geometrical adaptability and fully meet the requirements for outdoor use.

For the different materials different types of manufacturing technologies would be used. At this stage of our research, we only considered the feasibility of the manufacturing technologies, and the cost implications of production were considered later.

CONSTRUCT DESIGN, VALIDATION

The 3 concepts described above were developed in the second phase of the design process. The most suitable material for each design was selected from the possible materials: at this stage we also took into account the manufacturing technology and the likely cost implications of the material.

The following designs have been developed and prototyped:

- Version with truss beams

In this version, we tried to combine different types of materials. The tabletop is made of plywood and the surface is coated with a resin layer for outdoor use. The tabletops are assembled on a structural steel leg structure and a truss beams structure, also made of structural steel, is used. The metal parts are phosphated and then powder coated to ensure proper surface protection.

- Integrated rib version

This construction is made almost entirely (except for the "net") of aluminum alloy. There is no separate stiffening structure under the tabletops in this version, but the tabletop construction itself contains the ribs as a stiffening structure. Welding aluminum alloy during production is more complicated than for structural steel, but the material has the advantage of corrosion resistance: it does not require any special surface treatment to withstand the stress of outdoor use over the long term.

- Separate tabletop support frame and playing surface

For the third construct, different materials were combined: the legs of the table are made of structural steel, but the legs are not assembled in two parts, but four separate legs are made. A further important difference for the leg structure is that we also use a separate bracing, but for this we developed a curved rib rolled from a hollow section. We have also reworked the structural design of the tabletops: a truss support structure welded together from hollow sections provides rigidity, while the playing surface is made of a special composite material (HPL = High Pressure Laminated). [3] The composite plate was attached to the metal grid support frame by an "invisible bond", i.e. by gluing. This solution provides a completely clean playing surface, with no protruding fixings on the tabletop surface. For the

"net" element, we also used the same material (HPL) as for the playing surface: we glued several layers together with contact adhesive.

Once the prototypes were ready, we carried out a series of tests. The load test and the high speed camera test, as well as the climate tests, were only carried out on the 3rd construct, which we considered to be the best design option. In addition to the above tests, combustion tests were also carried out on the materials used for the construct. During the load test, the surface of the assembled table was loaded at several points on the tabletop with a 3,000 N load, and the deflection values were monitored using strain gauges. A rapid camera test was used to investigate the bounce of a ball dropped on a table: the ball was dropped from specific points and heights on the table, and the trajectory of the ball bounces was recorded using a special evaluation software. We also performed a fatigue test on the samples to simulate how continuous, cyclical ball bouncing affects the quality of the playing surface. The final part of the test phase involved climate studies, simulating the expected environmental climate loads for different paint coatings, materials and binders used. The main objective of these tests was to test corrosion resistance and UV resistance. [4] [5]

From the designs and prototypes, we selected the best one, which was the "separate tabletop frame and playing surface" design. This design is the fixed–type table version, which we have given the product name Teq One. Based on this design, in the next phase of the project we started to work on a foldable, mobile version as well, which we call Teq Smart. For the Teq Smart tables, there are also several different designs, but all of them are based on the same materials and technologies as the selected fixed–type table, thus unifying the technologies used in our different products.

For the Teq Smart tables, the most challenging part was the solution we use for the mechanism to provide the rigidity required for a Teq table while still providing foldability and mobility. In addition to the rigidity of the construct, we also consider the design to be very important, so we had to pay attention to this in the design of the construct. In order to achieve the necessary rigidity, the combined weight of the Teq Smart table's raised and lowered parts (tabletop, leg) is quite high, so we had to ensure ergonomic and safe raising and lowering, which we achieved with the help of a gas spring.

In the test phase, the full scope finite element simulations of the developed designs were carried out. The aim of these simulations was to investigate the load capacity, rigidity and stability of the tables as a whole structure. [6]

Once the constructs got approved, we were able to start obtaining the certificates, which we managed to obtain for the parent company of Teqball Kft. due to the intellectual property rights. Separate certification is required for the European market and for the North American market. The main challenge for the certification bodies was to find a way to test the equipment, but long negotiations resulted in success: we obtained a UL (USA and Canada) certification and a GPSD (General Product Safety Directive) certification for the European markets.

We have also prepared the necessary quality management and quality assurance standards for the finished constructs, against which the Teq tables are certified. The quality management and quality assurance are very complex systems themselves, as we have set high quality standards for our products. [7] We have prepared a lot of internal standards, work instructions for the quality management staff, the mass production quality control processes, the sample FMEA analysis protocols, etc.

MASS PRODUCTION PLANNING

Getting finished designs into mass production is one of the most complex parts of the whole product development process. Setting up the production equipment and production lines is essential for mass production, but logistics is equally important at this stage.

One of the crucial technological parts in terms of the manufacturing techniques is welding. In order to produce welded assemblies with the correct tolerances in terms of dimensions, precise devices are needed to position the parts to be welded. As a first step in the mass production, we have created provisional welding machines, which will be followed by mass production welding machines. The provisional machines have a simpler design, which makes them faster and cheaper to produce, however they are capable to produce up to 2,000 products only. These provisional welding devices are made for both the Teq One and Teq Smart tables. To complete the project, we will build the mass production welding machines based on the experiences we gained.

Another very important technological element of the constructs is the gluing of the tabletops. A flat HPL sheet is glued to the curved metal frame, thereby cold deforming it and fixing it to the metal frame by gluing. To ensure proper positioning, we have developed a gluing device that positions the parts to be glued and holds the playing surface itself under pressure until the glue sets. In developing the gluing devices, we have placed great emphasis on ensuring that during the adhesive curing period, these devices – and with them the tabletops under clamping – can be stored easily, with little space requirement and are easy to move. Gluing is a very complex process, and the technological description of the gluing process, which we developed together with the supplier. [8] To apply the gluing technology in large series, we have started to develop and adapt a technology to reduce the curing time of the adhesive from 48 hours to 8

hours. To do this, we need a special extrusion device called a Booster pump. The introduction of this into the production process is still in progress.

In terms of logistics, the biggest challenge was to transport the parts of different sizes and shapes at the same time. [9] We needed to develop solutions that would allow us to transport the painted products without damage, while maximizing the capacity of the available means of transport. In mass production, individual containers are always developed for the transport of parts, allowing both internal and external logistical processes to be optimized.

We have developed a "stocks" system, also used in the automotive industry, first for the fixed–type table and then for the folding version. With the Teq One table – because it is simpler and has fewer components – we have managed to use individual containers for each component. For the Teq Smart table, we have designed complex containers with several types of components due to the complexity and large number of parts. An individual container consists of two main parts: the metal support frame, which is the stocks, and the separators, which are placed inside it to keep the parts at a distance from each other, avoiding contact and damage.

The metal stocks are welded steel structures made of hollow sections, which must be able to support several tons of weight for certain components. Through continuous development, we have optimized the structure of the stocks, strengthening them where necessary and making them lighter where lower inertia sections were sufficient. We needed to make the stocks easy to dismantle so that they would take up less space when empty during return shipments and would be easily accessible during the packaging process.

The tabletops (both before and after gluing) are stored in a unique bag made of strong fabric, which is very easy and simple to handle. For the other components, a modular system of high–density technical foams, the so–called logistics trays, has been assembled. These logistics trays separate the parts from each other, and the high–density technical foam ensures that they can withstand loads of up to several hundred kg when stacked on top of each other in rows. For each part, the separator elements had to be designed individually to match the shape of the part.

The stocks and the separators together form a complex logistics system. During the development, we had to carry out a lot of tests: test unpacking and packing, test unloading, test deliveries, and we also had to test how the stocks or sets could be rotated between the different stations (e.g. between a supplier and the logistics center).

One of the most important elements of modern manufacturing is the supply chain, and within it, logistics. The current trend in manufacturing is for OEMs (Original Equipment Manufacturers) to focus on core or basic activities, while outsourcing all other functionality. Due to the fact that Teqball Kft. does not yet have its own manufacturing capacity, we had to outsource most of the manufacturing activities. This production organization in turn increases the importance of supply chain and logistics: many materials and parts need to be moved at the same time, and in a coordinated production process, they must always be in the right place at the right time. Reducing lead times is one of the most important goals in production optimization, which is best achieved by optimizing the internal logistics processes. As the concept of outsourced manufacturing means that there are many locations in the process, lead times are increased.

CONCLUSIONS

In this article, we presented the design process of an innovative product, the Teq table technology, in which we successfully solved the following tasks:

- selection of the raw materials
- selection of the technologies
- prototype production
- testing
- development of the quality management procedures and documentation
- design and development of the production technology
- supply chain and logistics system development
- development of the transport and storage equipment
- outsourcing

Within the R&D project, we could implement more manufacturing technologies that are used in the automotive industry. On the other hand, we developed the first serial producible Teq table and there is not compromise in the requirements. This generation of the Teq tables is really rigid, so the game experience on it is enjoyable, and can be used all around the world as an outdoor product.

We combined the different segments of the industries from the technology, used materials or requirements points of view. This kind of development does not happen so often, especially in the sports industry.

The development of the Teq tables is continued, we try to robotize the gluing process based on also the automotive industry and optimize the existing technologies, researching new materials or reducing the mass of each part of the Teq table.

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