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Roller Safety – the *faigle* view

Essay for the Chinese Elevator Association Special Safety Meeting August 2015

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Over the last 2 months, escalators accidents have drawn much attention from the public. There is a lot of potential safety risks in escalators, which is why they are considered as special equipment. As far as manufacturing, installation and maintenance are concerned, this requires the component suppliers of escalators to provide highly qualified products to ensure safe operation and use. As the World's longest running and most productive escalator roller manufacturer --- faigle company would like to take this opportunity to share and discuss with all participants, roller as a safety component of escalators.

faigle believes that safe rollers that are fit for purpose define much of the overall safety of an escalator. The main safety features that are engineered into rollers can be generalized as follows:

1. R & D Technical Design
2. Experience and Suitability of Manufacturer
3. Comprehensive Control of Materials
4. Understanding and Mitigating Environmental Influences
5. Quality Control, Assurance and Testing
6. The Erosion of Over-engineering and Safety Margins
7. Managing Price Pressure
8. Accountability of Unit Owners/Operators

1. R & D Technical Design

faigle uses advanced technical tools to understand the properties of rollers prior to prototyping and whilst still at the 3D modeling stage. The use of Finite Element Analysis (FEA) is fundamental to understanding the load distribution, stresses and pressures exerted on different roller designs. FEM analysis also makes predictions about how rollers will behave in different circumstances and in different applications.

Figure 1 shows a FEA of two rollers with different designs. The rollers are identical except for the way the tire is attached to the hub. The one on the left having an undercut (flanged design), and the one on the right without the undercut (*faigle* fused design).

The colors in the pictures show the stress levels as a result of loading simulated on the roller.

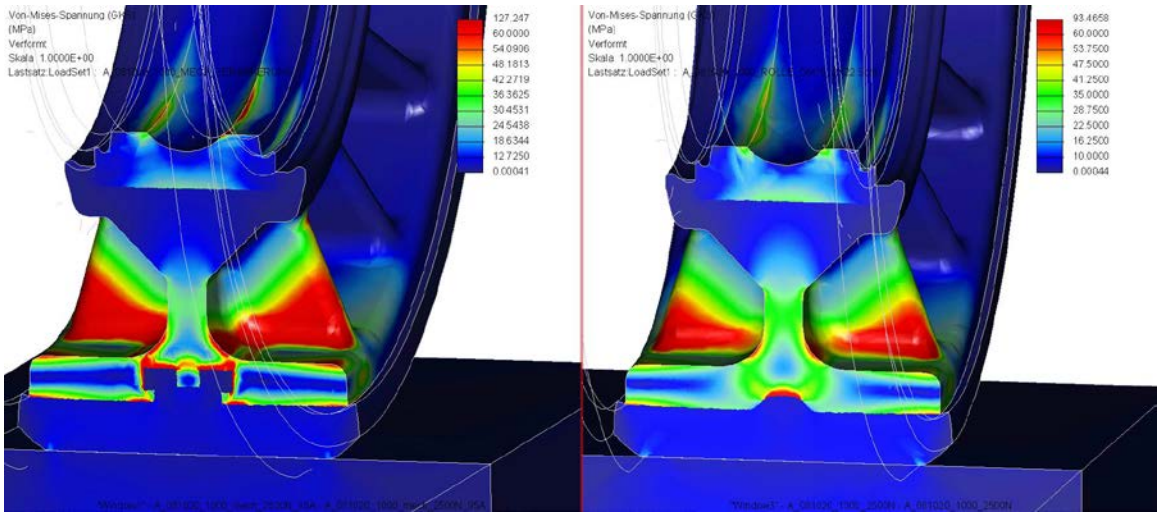

Figure 1. Finite Elements Analysis of a roller with flanged design (left) and fused design (right)

The left roller with the flanged design shows high stress at the corners of the connection between the tire and the roller hub. These stress peaks can lead to a damaging of the tire and the hub over time. *faigle* uses such design optimization techniques to lower stress peaks in the design of rollers which in turn leads to increased longevity and safety.

In addition, injection molded components such as plastic rollers benefit from Mold Flow Analysis (MFA), a complex mathematical modeling of liquid plastic flow within injection molds. MFA significantly deepens the understanding manufacturers have with regards to the production of these parts and is another essential tool in the development of safe rollers. *Faigle* uses MFA in the development of all escalator rollers and plastic parts.

MFA shows weak spots in injection parts, such as air pockets, filling issues, injection pressure instabilities, joints and interfaces and polymer surface temperatures.

Together FEA and MFA used in conjunction with 3D CAD establishes the core safety criteria of new products at the earliest stage of their development. These tools eliminate trial and error, because as stated earlier, error is not permitted for such important products.

2. Experience and Suitability of Manufacturer

faigle believes that there is no alternative to having deep experience in roller design, manufacturing and engineering when it comes to making a safe roller. Leading manufacturers such as *faigle* build a formidable degree of understanding in every aspect of the evolution, design, manufacturing, testing and use of escalator rollers. There is no safety relevant aspect of an escalator roller that is not completely understood. This depth of understanding across all facets of engineering, development and production ensures mistakes are avoided before a roller concept is even developed.

In addition to a having deep technical understanding of each specific product line, *faigle* for example, employs only technicians with minimum degree level education in the areas of plastics chemistry, material science, technical design and plastics engineering. The principle of apprenticeship is also widely used to teach real industry know-how to the junior employees that will become future supervisors and managers. This bedrock of knowledge is key to any Engineering Company's success,

The ability to completely understand the product and therefore guide customers in the choice of roller for their specific application becomes a key part to the long term safety and therefore business survival of market leading escalator manufacturers. It is therefore neither a surprise nor a coincidence that the most successful escalator manufacturers are also the biggest users of tier 1 roller suppliers such as *faigle*.

3. Comprehensive Control of Materials

Fundamental to the quality of product is the assurance and quality control of incoming raw materials; the control and strict management of re-use materials; and ongoing critical review of vendor suppliers. These three aspects in conjunction with routine but extensive in-house testing allow manufacturers to assure the quality and reliability of their products.

In 2010 *Faigle* opened the PAS®- Center at their manufacturing facility in Suzhou. This materials laboratory is designated with the task of 'Total Quality Control'. This concept requires that every batch of every inbound material and every batch of outbound product undergoes an extensive panel of quality checks, tests and assessments. Dimensional, chemical, physical and endurance tests are performed by highly qualified operators to check a wide variety of parameters. Even in-process testing is routinely performed to provide assurance that each key step in the manufacturing process conforms to established standards. By measuring every batch from every product line, the PAS®- Center's engineers add a substantial degree of assurance to *faigle's* product portfolio.

The PAS®- Center's extensive testing includes a 5000 hours (7 month) continuous high load running test in order to prove the lifetime of the roller. Most manufacturers only test for 20% of this time which *faigle* believes is insufficient for the assurance such a safety part needs. It is also clear that roller failures most commonly occur after significant use, so extended testing is required to discover any fault rather than a short running test which hides any long term problem. *faigle's* in-house lifetime running test rig is *faigle's* own design and the envy of the roller industry. The systems were a major investment in the long term sustainability of the *faigle* brand and are used to assure every roller design. All roller manufacturers should have a dedicated professional testing facility aimed at the comprehensive lifetime assurance of escalator roller safety.

Recycling has become synonymous with environmental performance and all modern companies, especially market leaders, are expected to demonstrate a high degree of environmental responsibility which includes the recycling of their own reusable waste materials and by-

products. However the incorporation of recycled plastics into injection molded escalator rollers brings compromises in the uniformity of the overall physical and chemical properties of the roller product. Whilst it may seem that the use of recycled plastics makes both good commercial sense and good environmental practice, recycled materials are potentially a threat to the reliability and conformity of rollers and therefore the safety of rollers. This is particularly true for products that manufactured close to the limits of their tolerances and where safety margins have been eroded (see below). Strict control and an exact understanding of re-use and recycled materials is therefore essential to control and mitigate any negative influences these materials introduce into manufacturing systems.

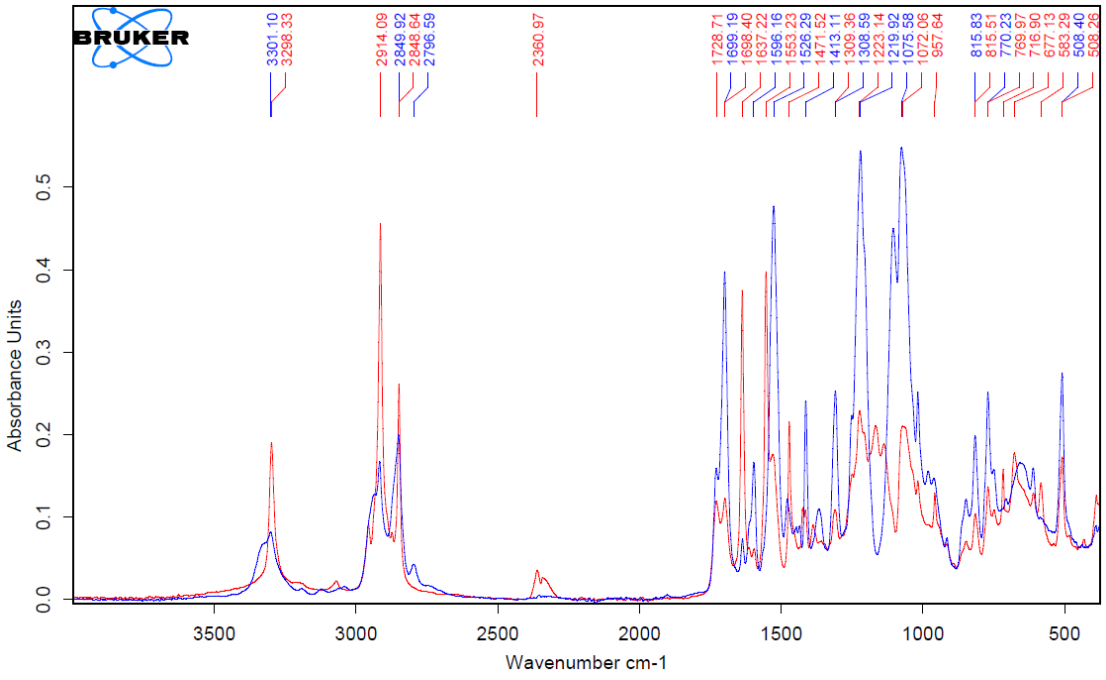

Figure 2: Infrared analysis of two different TPU samples

Figure 2 shows an infrared analysis of two different TPU samples. The red curve is a Thermoplastic Poly***ester*** type, while the blue curve is the trace of a Thermoplastic Poly***ether***.

This procedure is used to determine the molecular construct of plastic material and can be seen as a fingerprint of the plastic. It can also reveal mixtures of different types of plastic and filling material. It is important to always check and document the quality and purity of incoming raw material.

faigle, with its testing centers in Asia and Europe, utilizes the latest high technology testing devices such as high definition cameras, infrared analysis of material samples and thermal analytics. These tools and methods provide the scientific basis for guaranteeing the quality of product. *faigle* believes that these scientific procedures should be made standard requirements for the protection of roller safety and therefore public welfare.

4. Understanding and Mitigating Environmental Influences

It is true that plastics are an excellent material for the manufacture of escalator rollers due to the highly resistant characteristics of the materials used. Most typical chemical, physical and environmental factors do not affect the longevity and reliability of plastic rollers. However there are risks from environmental factors that whilst often rare, can cause catastrophic failures. Most companies work on the principle of material risk management i.e. the smaller and less frequent the risk, the less resource is attributed towards the control of that risk. This is defendable in non-safety parts, but it is inexcusable in safety parts.

Risk, no matter how small and unlikely must be controlled at all times. Take for example the environmental factor 'Water Hydrolysis' in the degradation of Thermoplastic Polyurethane (TPU).

TPU is widely used in roller manufacture to provide the tire for rollers. The tire is the surface upon which the roller runs and through which load is transferred to the escalator running rail. Virtually all escalator rollers are manufactured of TPU in this way. Hydrolysis is a natural chemical process whereby atmospheric water attacks and splits polyurethane molecules leading to cracking of the plastic tire and the eventual loss of mechanical integrity of the roller. Rollers that undergo hydrolysis in application can lead to failure of the step and chain system integral to the safe running of escalators. This is not an outdoor phenomenon, even rollers within acclimatized rooms such as shopping malls undergo hydrolysis.

Polyester type Polyurethanes are not hydrolysis resistant and need an additive to be stabilized against hydrolysis. Polyether Polyurethanes are resistant to hydrolysis. Hydrolysis resistant TPU costs more than hydrolysis stabilized however, so many manufactures do not use it, or use weak blends of it. *faigle* is the only manufacturer that uses exclusively hydrolysis resistant Polyurethane, a key determinant of roller safety.

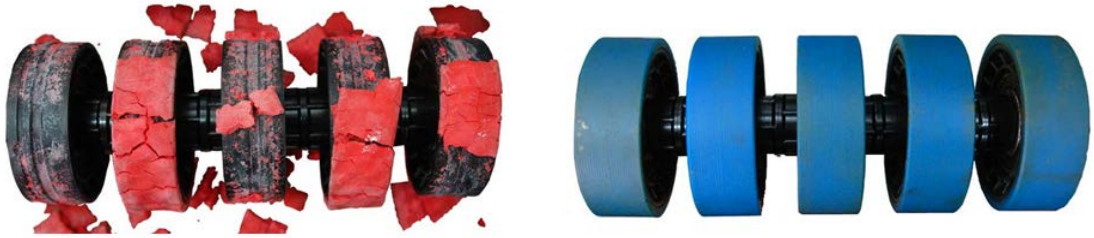

Figure 3: Left side roller tire made of hydrolysis stabilized Polyester Urethane; Right side *Faigle* roller tire made of hydrolysis resistant Polyether Urethane

Figure 3 shows a roller with a polyester type TPU tire and a roller with a polyether type TPU tire. After the same treatment time in 80°C hot water steam both rollers show a different picture of damage. While the blue roller with hydrolysis resistant material is still without any visible damage the red hydrolysis stabilized material has completely disintegrated. These rollers are designed for either escalator step or chain and losing a tire in this way can cause the step to drop by up to 1 cm, a major risk to passenger safety.

Figure 4: Real Life Roller Failures

Singapore – 4 years in Operation

Portugal 2002, 8-9 years in operation

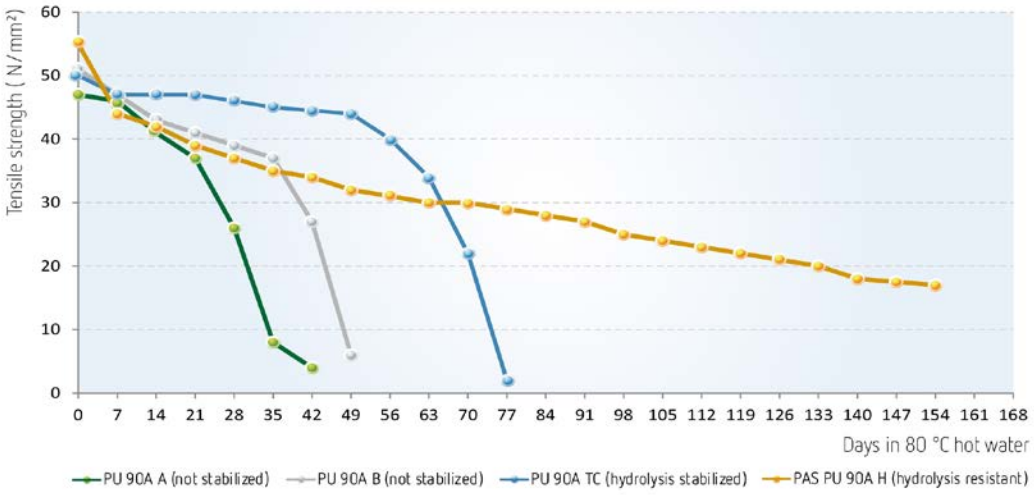

Figure 4: Tensile strength of different TPU over days in 80°C hot water environment

Figure 5 shows how non-stabilized (green), stabilized (grey and blue) and resistant (yellow) TPU degrades due to Hydrolysis over time. In this test, samples were put in 80°C hot water and then tested for tensile strength.

The results clearly shows that there are TPU's that do not meet the technical requirements for being an escalator roller.

This also shows that while mechanical values can be good at the start, can quickly degrade due to environmental influence over time and ultimately fail to meet their designated technical function.

Severe hydrolysis only affects a small proportion of TPU rollers but when it does the result can be catastrophic. It is possible to completely eliminate the effect of hydrolysis in polyurethane by using a hydrolysis resistant material, but this is not widely used in the roller manufacturing industry due to its higher cost. However, in order to eliminate this risk from its products, *faigle* only uses hydrolysis resistant polyurethane.

By investing in better materials that convey additional safety and lower risk, despite the availability of similar, cheaper but less effective materials, *faigle* removes this and other environmental risk factors from escalators, thereby protecting the public, the manufacturers and itself from this risk.

Understanding and mitigating environmental influences is a key part of the detailed material science needed to effectively deliver safe products. It is not enough to merely copy design and choose similar materials and construction methods. Paramount to safety is this deep and comprehensive understanding of the product in application, in field and exposed to the ravages of the operational environment. *faigle's* view is that the escalator industry does not place enough emphasis on the comprehensive control of environmental influences in the manufacture of rollers.

5. Quality Control, Assurance and Testing

In section 3 it was explained how the *faigle* PAS®-Center controlled both inbound materials and outbound products. Specifically in this section we discuss roller testing and the regime of experiments that build to provide Quality Assurance.

QA is applied to physical products in pre-production to verify what will be made meets specifications and requirements, and during manufacturing production runs by validating lot samples meet specified quality controls. ISO 9000 defines it as a key part of the Quality Management system that focuses on providing confidence that quality requirements will be fulfilled. For *faigle*, a company that has established a worldwide brand based on quality assurance, it is a living part of every aspect of every process within the Company.

Holistic Quality Assurance is not just a series of tests that build data confidence, it is a mindset, a culture and a vision, created by leadership, defined by decision making executed by employees. Sometimes it is recognized by customers, but this is not the sole purpose. Quality Assurance builds business sustainability as well as market trust. It guides the evolution of business relationships.

Taking a holistic view of Quality Assurance has been one of the main benefits customers have enjoyed through working with *faigle*. This in turn has elevated both *faigle* and its customers to market dominant positions.

6. The Erosion of Over-engineering and Safety Margins

In today's commercial escalator environment, profit margins are very thin. It is typical for manufacturers and their suppliers to experience periods of loss given the vagaries of raw material prices and continuous downward pressure by purchasers on component pricing. Such pressure forces component manufacturers to continually review manufacturing processes, tolerances and materials. All these can lead to a reduction in manufacturing costs through generating efficiencies and achieving process optimization. It can also erode safety margins.

Historically parts such as escalator rollers were engineered with significant safety margins built into the product. Typically design specifications such as loading, lateral and axial forces, environmental influences, running speed, material type and composition exceeded actual operating specifications by a healthy amount, creating the safety margin over and above the specification required by the application. Optimization and price pressure has eroded these safety margins over timer and today it is normal for a product to have a very small margin of safety engineering in excess of the operating specification. This concept of product components being 'just good enough' introduces risk especially when components are exposed to atypical conditions in field. Over-engineering creates room for non-conformance in operations but the erosion of safety margins in materials, design, construction and testing allows nonconforming situations to reach or exceed the safety margin threshold.

Expansion of and increased adherence to national Type Testing has worked to counter this effect and create a minimum acceptable tolerance for key specifications such as loading. *faigle* is pleased to see stronger and more robust national specifications coming into force alongside safety margins increasingly being specified by end users and escalator manufacturers that drive down risk and select for quality component manufacturers that deliberately over-engineer safety parts.

The *faigle* view is that 'just good enough' is not good enough. Safety parts must not only meet the minimum requirements but must strive to both increase safety margins whilst meeting the commercial expectations of customers.

7. Managing Price Pressure

End users are more informed today about material costs and prices than at any other time in history. Customers can instantly get access to global and regional raw material prices, comparative information between suppliers and a wealth of other information that equips them to negotiate from a fully informed position. As a result of this and increasingly aggressive competition amongst escalator manufacturers, end user pricing has sharply declined over the past decade. Today escalators cost far less than ever before and the entire supply chain has undergone a substantial reduction in value.

Manufacturers of escalators continually remind their supply chain that cost reduction must never lead to quality reduction, but this is unrealistic and perhaps sometimes naïve. Price reduction in the supply chain does inevitably lead to erosion of quality and the simple truth is that escalators are too low cost for the degree of engineering involved in their manufacture. This is not only true for escalators but is a widespread concern in many manufacturing sectors.

The counteracting force to downward price pressure is to create additional value for the buyer. Improving supplier performance, consolidation of services and harmonization of interrelated processes being three examples where improved value can be introduced into the buyer: supplier relationship in exchange for maintenance of existing price levels. But the fact remains that price pressure will continue so long as customers have access to information and shareholders demand increasing returns. It requires a sophisticated partnership approach between buyers and suppliers in order to collectively maintain sufficient margins for all parts of the supply chain to remain healthy.

8. Accountability of Unit Owner/Operators

faigle has limited direct knowledge of the situation of escalator owners and operators, however it does seem clear that the responsibility for maintenance is not entirely clear in the marketplace. In some cases responsibility for maintenance does not remain with the owner or operator of the unit but instead is contracted out to the manufacturer of the unit or a nominated maintenance company under the terms of a maintenance contract. Whilst this may be appropriate for scheduled maintenance e.g. on an annual basis, it may not be appropriate for

ad-hoc maintenance or unscheduled maintenance. Ultimately the responsibility and accountability for maintenance of units in operation should lie predominantly with the operator of that unit. Safety should not be outsourced, it must be managed directly by those who oversee daily operation of the unit and accountable by them to users of the escalator for its safe operation.

Summary

Faigle commands a leading position in terms of innovation, quality, market share, customer loyalty, and productivity. The global escalator industry (including all of the major escalator OEMs and many of the regional and local escalator manufacturers) rely on *faigle* for the majority of escalator roller products.

As an Austrian Company, *faigle* is rooted in the geographical heart of 'European Engineering'. It is from this technical and engineering environment that the *faigle* Company began and then came to dominate the supply of escalator rollers across the World.

Escalator rollers are a fundamental safety part. The escalator chain and steps are both heavily reliant on the quality and safety of the rollers. Roller failure is therefore not an option and as such the technical quality assurance of rollers is paramount to the safety of the whole escalator system.

The terrible events of August 2015 have been a tragic reminder of the importance of escalator and elevator safety to all suppliers, manufacturers and operators of these units. It is totally unacceptable that people die or are injured through normal use of these machines due to defective parts or defective operation.

For *Faigle* Company there is no comfort in the fact that our rollers are amongst the safest and most carefully engineered and produced parts within these machines. The safety of the whole machine is the sum of the safety of its component parts. Put another way, escalators are only as safe as their weakest part. Merely having safe rollers does not make safe escalators. Greater efforts must be made by all parties in the design, component supply, manufacture, operation and maintenance of escalators to protect public safety.

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