LAST BUT NOT LEAST – RESULTS OF FINISH PROCESSING CAN SAVE OR DISTURB YOUR EFFORTS [1]

Latest Trends And Technologies For Modern Thin Gauge Slitting Lines

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Abstract

The market is increasing its demands on plant performance and expectations in terms of high-quality products, maximum productivity and high plant availability, requiring the constant improvement of machinery, control systems and strategies. Specifically high demands are placed on plants for rolling, slitting, cut-to-length and trimming of thin strips. With continuous operation and with long strip length it is absolutely necessary to achieve the best reproducible rolling and cutting results. In doing so, emphasis is placed not only on the strip width tolerances but also the strip edge quality and the flatness over the complete strip length. Modern concepts have been developed by Danieli both for the mechanical and electrical/automation components of the lines to address these issues. Thereby, optimisation of existing design with respect to bearing distance and other detailed solutions have led to the increase of total stiffness of slitting shears. New braking systems have been developed that do not expose the material to friction during the tensioning process before recoiling.

Key words: Slitting; Braking; Cutting.

ÚLTIMO, PORÉM NÃO MENOS IMPORTANTE – RESULTADOS DE PROCESSOS DE ACABAMENT PODEM SALVAR OU PERTURBAR SEUS ESFORÇOS

Últimas tendências e tecnologias em Linhas Modernas para Cortes de Bitolas Finas

Resumo

O Mercado está aumentando suas demandas quanto ao desempenho de plantas; e expectativas em termos de produtos de alta qualidade, máxima produtividade e alta disponibilidade da planta, requerendo a constante melhoria das máquinas, sistemas de controle e estratégias. Altos níveis de exigências são comuns especificamente em plantas para laminação, corte longitudinal, corte transversal e refilamento de tiras finas. Com operação continua e com longos comprimentos de tiras é absolutamente necessário atingir os melhores resultados possíveis em laminação e corte. Sendo assim, a ênfase é colocada não apenas nas tolerâncias de largura da tira, mas também na qualidade das bordas e da planicidade sobre todo o comprimento da tira. Conceitos modernos têm sido desenvolvidos pela Danieli para componentes mecânicos e elétricos/automação das linhas para atender essas expectativas. Assim, a otimização do projeto existente com respeito à distância dos rolamentos e outras soluções detalhadas têm conduzido para o aumento da rigidez total das tesouras de corte longitudinal. Novos sistemas de tensionamento têm sido desenvolvidos para não expor o material a deslizamentos durante o processo, antes de rebobinar.

Palavras-chave: Corte longitudinal; Tensionamento; Corte.

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Introduction

Danieli Froehling provides machines and technology for the metals industry, particularly in the field of steel, copper/copper alloy/brass/ bronze as well as aluminium and aluminium alloys. Our scope of supply comprises:

- Cold rolling mills, designed as tandem mills, 2-, 4-, 6-, 12-and 20-high mills (and combined mills) for steel, aluminium and copper alloys
- Auxiliary equipment for cold rolling mills (for instance in-line roll polishing devices)
- High speed trimming lines
- Slitting lines
- Cut-to-length lines
- Wide milling machines for copper alloy strips
- Associated services for this kind of industry (like spare parts service, modernisations, single machines etc.).

Being a major supplier with world-wide references, Danieli Froehling is an appreciated partner and provides state-of-the-art know-how due to knowledge gathered in a large number of applications for the above mentioned equipment. Lines and equipment have been supplied (amongst others) to ThyssenKrupp, Theis, Wieland Group, KME, Luoyang Copper, Shanghai Copper, DIEHL Group, ALCOA, ALCAN, HYDRO Aluminium, and various others. Due to constant improvement and development of our machines in connection with continuous exchange of knowledge with plant users we are in the position to offer sophisticated solutions that fulfil today's requirements regarding productivity, reliability, long life-time availability, short pay-back periods and best final product properties. Some of these developments will be explained in this paper.

The ever increasing quality requirements of finished strips, both of non-ferrous and steel materials lead in turn to tighter tolerances for semi-finished material. Subsequent treatment (for example stamping) is currently characterized by a high degree of automation with the fastest processing speeds in order to achieve production volume as well as low material wastage.

As a result of the above, the properties of the semi-finished material become more and more important especially concerning geometrical dimensions, burr and shape. Besides the metallurgical fabrication of the material itself and the rolling process, dividing (cutting) of strip is the essential parameter that influences the strip quality.

Uneven widths, increased edge burr as well as stress in the material could result from badly adjusted or designed slitting or cut-to-length shears. Moreover, the tensioning process before rewinding and the rewinding procedure itself have a high impact on the quality of the finished strip respectively sheets as well as the diameter of rewound slit strip rings.

Life cycle cost considerations

Danieli Froehling has never been recognised as the cheapest supplier in the market. But customers have understood that the advantage of using high-class technology and equipment is of more value than just the "initial price" to be paid. The holistic understanding of life-cycle costs of investments becomes more and more accepted, especially on the international level of leading strip producers. This means, that costs of machines have to be considered as a sum of costs over their total life-time. These costs are influenced by (but not limited to):

- Initial price (purchase price)
- Maintenance frequency
- Necessity of spare parts
- Costs for operators of the line
- Cost for unexpected and expected repair
- Costs for consumption materials (power, oil, water, …)
- etc.

Only about 15 – 20 % of the total lifetime cycle costs are related to the purchasing price of the equipment. The costs during operation from start of production until end of production are much higher – in many cases 4 to 7 times higher! And this is the point, where the investment can pay back – with reliability of machines, low maintenance costs and high productivity, low scrap amount, best qualities of finished products (and therefore better prices achievable), short coil-to-coil time (resulting in higher productivity) and long lifetime of the equipment in general.

Especially final product tolerances as well as higher productivity of lines are the main factor in the life cycle cost considerations. High productivity is influenced by management of plants (production planning) but the equipment and its reliability as well as automation degree and special features are essential as well. “Special features” can be sophisticated solutions for coil charging to/off the coilers, tool and/or mandrel changing devices, threading of strip and generally equipment and design that reduces the line’s downtimes and therefore increase the real production time.

Considering cutting line equipment, the following parts of lines have the highest impact on finished product quality and special attention shall be paid to this equipment:

- Slitting shear
- Braking/tensioning unit
- Recoilers

Of course, all equipment with direct contact to the strip surface (rolls, guides, mandrels etc.) is potentially dangerous when considering scratches. It has to be assumed that both manufacturing and adjustment of such equipment is on an exceptionally good level and right materials and surface finish have been chosen for this equipment.

Generally, Danieli Froehling warrants that the strip properties are not worse than at the entry side and

- No wavy edges are caused by the correctly set-up slitter.
- No wavy areas at strip centre are caused.
- Deviations from straight line are not worse than at the strip input.
- No marks or scratches are visible, that resulting from the lines equipment.

This requires very accurate equipment but it also calls for best possible electrical adjustment of drives especially concerning tension and speed adjustment. Further, the cooperation of the operating personnel is an essential factor that has to be pointed out – it also needs the right attitude and skills of the person who operates the equipment.

Slitting technology

As the requirements for “totally” flat material with tight tolerances exists not only for finished rolled material but also for the slit strip, development of even more precise and rigid slitting machines is of highest importance. Often, the strip finishing equipment is the last in a long line of investments and investors try to save money just at this point by applying simple and cheap solutions. What they often fail to realise is that the final product as the customer sees it will be produced at the slitter or the cut-to-length lines respectively. All positive results gained in upstream processes can be destroyed if the cutting quality does not satisfy customer requirements.

Shearing stresses have a big influence on subsequent workability of the strip. Single strips may curl or even jump out of the stamping die if stresses induced during slitting are too high. Beyond this, increased burr might occur which would lead to material getting stuck in the die. Width deviations could result in imperfect shapes due to the very narrow trim web at the edge of the strip before pressing.

The development of CNC (computer numerically controlled) slitting shears dates back to the 1990's. The idea behind this development was the understanding that material – depending on its mechanical properties like tensile strength, elongation and its geometry – would be sheared at a certain degree part way through the thickness and the remaining part would fracture.

The "ideal" cut is characterised by a defined relation between cutting and fracturing of the material itself. The closer the knife immersion meets these "ideal" conditions, the better the appearance of the cutting edge will be. Furthermore, the lower the immersion depth the less stress will be applied to the strip. With highly accurate adjustment devices, modern slitting shears provide the best chance of an exact and repeatable knife shaft adjustment. The other essential parameter in addition to the immersion depth is the cutting gap, i.e. the horizontal clearance between the upper and the lower knife. Both too small and too wide a gap results in an uneven breaking zone and in non-ideal angle of strip edge to the strip surface. This can be influenced by having high quality cutting tools but also the lowest axial run-out of the knife shafts.

The actual cutting operation contributes to the material stresses. Plastic deformation happens when cutting is done and results in a more or less developed local hardening of the edge. This causes differences in material strength across the strip width. These different material strengths could lead to curling and/or camber of the material.

The material properties, especially material strength and strip thickness, of the strip itself have a considerable influence on the cutting quality. As a result of this it can be seen that the slitting shear must be able, utilising a data base available from the line's automation system, to be adjusted as closely as possible to certain parameters (immersion and cutting gap) according to the material conditions. The cutting gap is normally determined by using the right dimensions of the cutting tool spacers. This combination of spacers and knives would be chosen according to a tool setting program which is provided by the tool suppliers. The immersion of the knives will be realised by the shear setting taking into consideration the actual tool (knife) diameters. Manufacturing must be precise and to within given tolerances. This is essential for thinner strip gauges in particular. Furthermore, repeatability of this shear setting has to be guaranteed and it must be ensured during the cutting procedure as well.

Danieli Froehling realises all the related features by a high standard of design and manufacturing:

- Pre-tensioned elements, such as ball roller spindles, special bearings and linear guides giving backlash-free movement of the important machine parts.
- High accurate measuring systems are available to provide the adjustment system with the necessary data. Measurement accuracy at Danieli Froehling CNC slitter is ± 0.5µm.
- Strong and heavy design in order to prevent the unit from vibrations.
- Data bases storing recipes for different slitting programs that may be recalled at demand
- Axial and (if required) radial clamping systems for the cutting tools ensure reliable clamping, according to request also automatically actuated

According to strip thickness, material, tolerance requirements and other factors, the most suitable technical solution for a slitting shear may be chosen after detailed calculations of cutting force, shaft bending and other parameters. Reliable calculation programs are available within Danieli Froehling for the design and development phase. Such, optimise slitting schedules may be arranged. Furthermore, these calculations will be one basis for the slitting recipes provided within the automation system later on.

Following these demands, Danieli Fröhling developed a new generation of slitting heads: the Super Slitter. One of the main parameters for the strip edge quality is the knives' immersion into the material to be cut. The optimal immersion depends on material grade, condition and strip thickness. The real immersion is a function of cutting force and machine rigidity. Part of the machine rigidity is the deflection of the knife shaft (Figure 1).

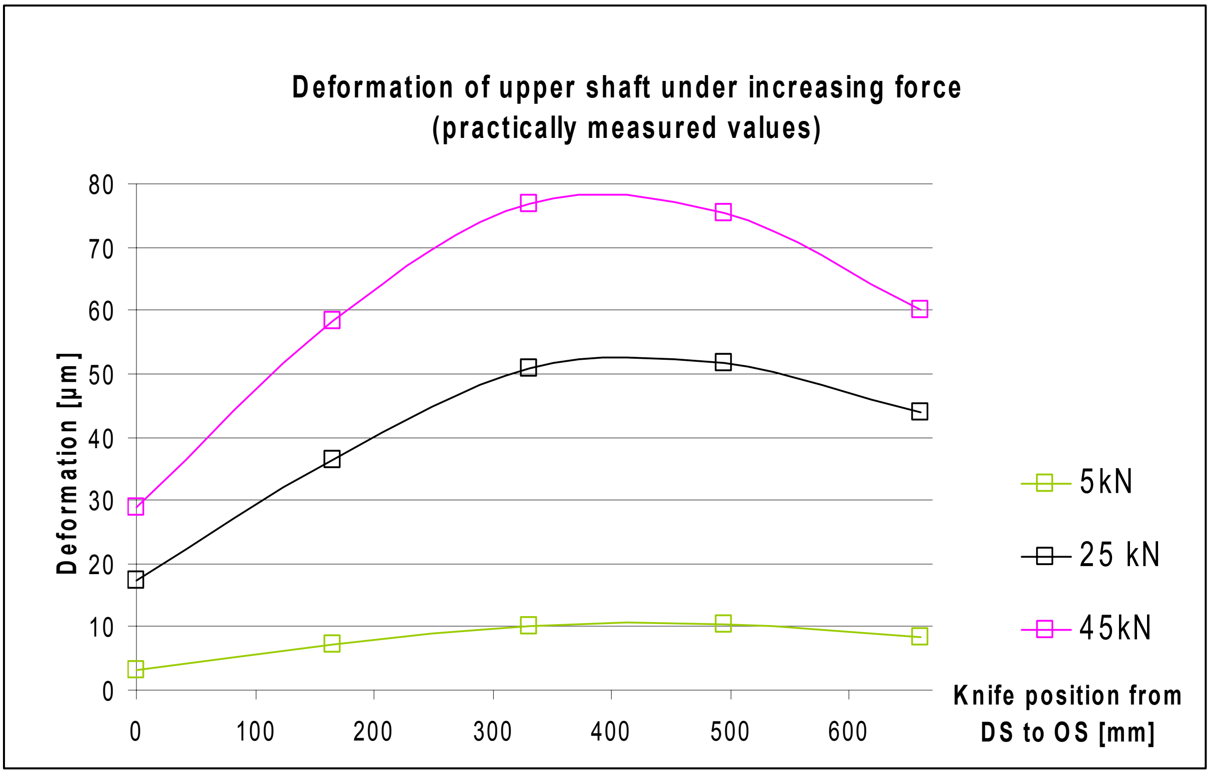

Figure 1 – Knife shaft deformation

If there are, for instance, 30 knives mounted on one knife shaft, the immersion of every knife depends on the axial position of each knife. By reducing the bearing distance and optimisation of the whole bearing system, a reduction of deflection by

44% is achieved with the newly developed slitting head. A crucial factor for the development was the improvement of the main parts by FEM analysis. To support the FEM analysis and to check it on a practical level, a simplified model was built in Danieli Fröhling's workshop. Loading with hydraulic cylinders simulated the cutting force and gave reassurance and further information to optimise the design. The remaining components which contribute to the machine rigidity are also important. This influence was reduced through the new design of the slitting head by 91%. Naturally this part was high-precision measured and compensated by a closed-loop position control. The stiffness of a knife shaft could be increased by more than 130%!
Because of the development of the slitting head with optimal machine rigidity, the immersion of all knifes is much closer to the ideal. This results in even better, reproducible cutting edge quality and a lower transfer of cutting stress to the strip. These conditions, combined with the right cutting gap, led also to an increase in knife service life. Looking from the position of given material properties, the development of the new slitting head makes it possible to reduce knife diameter and consequently costs. On the other hand, it will be possible to adapt the knife shaft diameter to existing tools to obtain an even stronger machine design compared to the previously used machine.
The first installations of the new Super Slitter have been in two German companies where the machines have been in constant operation since nearly 3 years. Both customers are completely satisfied (Figures 2 and 3).

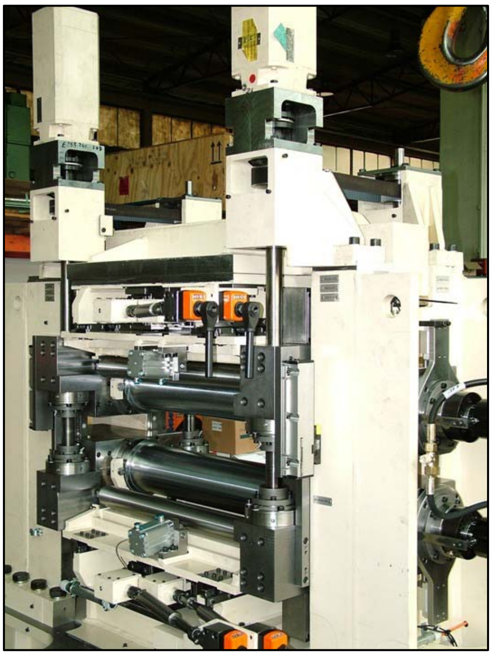

Figure 2 – Slitting shear

Figure 3 – Detail of slitting shear

The following control and automation elements will be adopted:

- Production tracking
- Production reports
- Automated process set-up
- Speed and tension control
- Level 2 automation system.

Thanks to the high level design of mechanical components acting together with the automation and control systems, repeatable set up of the slitting unit will make the operators work much easier. "Recipes" for the cutting programs can be entered into the system and recalled when applicable. The data base for these recipes is expandable as new strip dimension-property combinations will no doubt come along in the future.

Advanced braking units for sensitive materials

Vacuum roll

In longitudinal slitting lines, a looping pit is applied for compensation of the different recoiler diameters of the single strips – caused by the differences of single strip cross section due to the rolling process. Due to the down-gauging of finished products nowadays and the request of the finishing industry for larger and larger recoiler diameters, tensioning of the strip with advanced braking units becomes more and more important.

Braking is normally effected with a strip press and/or with braking rolls. These systems have different disadvantages, such as damage of the surface by high contact pressure, contamination of the brake linings, different strip tension at the strips, etc. Some of these disadvantages influence the material quality; others are unusable for large coil diameters, thin materials, etc.).

Danieli Froehling has developed the vacuum braking roll (Figure 4) in order to avoid or minimise the above mentioned disadvantages. About 25 of these units have been supplied to industry to date, and experiences have been gathered over the past about 15 years.

Advantage compared to the strip surface:

- No damage of the strip surface.
- No friction between upper surface of the strip and braking means lowest possible friction at the lower side of the strip.
- Same specific strip tension at all strips.
- Very low surface pressure during the braking process.

As a result of this technology, recoiling diameters can also be increased compared to conventional braking technology. The technical main data which are possible can be seen from the following:

Strip thickness range:	0.02 to 1.2 mm
Slit strip range:	9 to 2300 mm
Max. number of strips:	120
Specific tension:	~ 15 N/mm^2
Max. strip speed:	800 m/min

Figure 4 – Vacuum roll

The unit consists of a multiple-perforated steel roll connected to the vacuum unit via piping. The roll itself will be covered during operation with a special fleece material. Thus, the strips have no contact with the steel roll itself. The cover can be easily exchanged when worn or contaminated. Exchange of the cover material takes only a few minutes.

The strip tension that can be applied is a function of the weight of strip loop, air pressure, radius of the roll and the wrapping of the slit strips around the roll. As expected, various factors are variable and so, the strip tension has to be controlled by varying the pressure in the roll. $e^{\mu\alpha}$ has to be influenced by varying the rotation of the roll to a certain degree. The weight of the material may be “supported” by different means to increase this factor if necessary.
The automation system of the line is able to provide accurate pre-adjustments of the chosen factors when strip data are entered beforehand. The design of the roll has been optimised to achieve best possible results both for the tension and size of the equipment. Nowadays, this equipment has been used for enhancement of existing lines as well.

ECBS

A new development on the market for the braking systems is the Eddy Current Braking System (ECBS). This development is based on magnet technology which has been used in the separation of non-ferrous scrap in recycling, i.e. the technological principle has been taken from a different field of industry. Danieli Froehling and its partner have driven the development from a laboratory state to full production capability. Tests with several materials (alloys) in combination with different thickness and slit strip widths were run in order to gather exact design and operation parameters and to design a product that can be delivered in different modules according to the real applications of end-users.
An adjustable tension can be implied to the metal strip without using additional braking devices by means of the rotating magnet system. An induced moment (resulting from the torsional moment of the eddy current) is generated which allows design and construction in a very space saving and reliable manner. Previous disadvantages of eddy current systems were eliminated by application of a different working principle. Therefore, his eddy current brake can bear the function of the main braking (tensioning) unit for a complete line.
The new eddy current braking device for strip finishing lines is the first one of its kind which provides technology that is reliable and easy to operate. The hitherto existing devices have as the main advantage that the braking force drastically reduces with decreased strip speed. Furthermore, heat will be generated which might influence both the braking effect and the mechanical properties of the material. Only very large systems can suppress these effects but they are not practical with respect to later incorporation into existing lines and problems with material guiding.
As a result of the research and development work the following features have been implemented in our device making it unique:

- A counter roll with outboard bearing forces the strip to stay in the respective braking area
- The control of braking force can be adopted by simply varying the distance of counter roll to braking roll.
- The vertical force implied to the strip acts as additional support for keeping the strips in position and prevents tilting of the strips.
- Very compact design (also suitable for later extension / enhancement of lines) with effective and variable braking force.
- Control of braking force in a closed-loop configuration. Such operation of equipment is easy and user-friendly.
- Low consumption of operational and spare parts.
- Unit may be used for slitting lines and/or recoiling lines.

All disadvantages of previously available systems have been eliminated. The unit Figures 5 and 6 is suitable to act as the one and only main braking system in the line. Braking force can be adjusted and controlled according to the actual working conditions and is independent of the actual strip speed. Influencing factors are mainly the distance of the roll to the strip and the speed difference between roll and material. Furthermore, the strength of the magnetic field has to be chosen according to the material properties (alloy and thickness-width ratio).

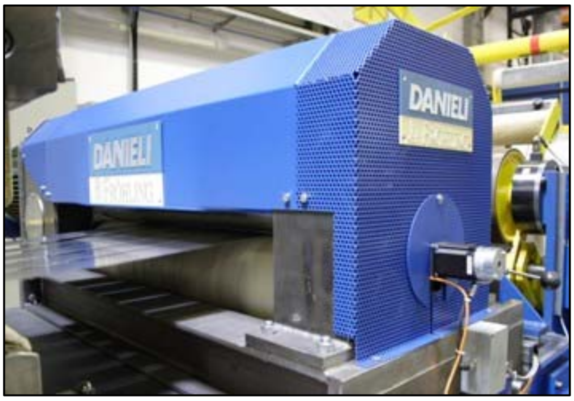

Figure 5

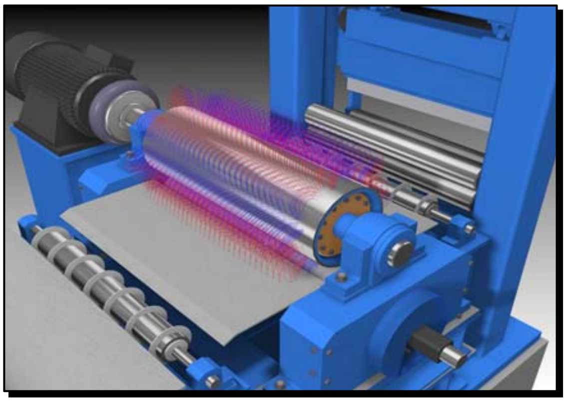

Figure 6

Recoiling process

Winding tension is the single most important parameter in the recoiling process. The optimum tension depends on product characteristics (geometry of the strip, strength of the material) and other winding factors. Mainly the strip thickness and width must be used to calculate the winding tension. Thereby it is obvious and well known that the tension is a result of force and area (cross sectional area). Normally today, the force of the rewinder in a slitting line is estimated by recording the rewind armature current, armature voltage, line speed and motor/system efficiency. To measure the force in a direct mode, load cells may be implemented on a roll upstream of the rewinder which is still an exception in a slitter.

To obtain a perfectly wound coil, different factors have to be observed. Tension is just one of these which have to be adjusted according the above mentioned factors. This leads to the fact that interaction between recoiler and braking system is essential in slitting lines using a looping pit. Other factors are:

- Alignment of all rolls between braking system and recoiler
- Alignment of the recoiler mandrel itself (and probably outboard support depending on coil weight and mandrel diameter)
- Design of the recoiler mandrel (or spool)
- Too much air in the coil due to thick edges and higher line speed
- Lubrication of the strip
- Different tension within one coil of a rewinding process (due to line stops etc) or different tension from one slit strip to another (due to rolling profile of strip)

Alignment of rolls and recoiler mandrel is a question of accuracy in manufacturing and commissioning processes. It shall be assumed that this is easy for an experienced plant supplier and its commissioning personnel. The design of the recoiler will have an influence mainly on thinner gauges and of course higher line speeds.

Danieli Fröhling uses 6-segment-mandrels for all its slitting lines as a basic principle. Thereby, it will be ensured that at nominal mandrel diameter every one will be absolutely round in shape and without any screw holes or other surface openings.

Markings on the strip occur for less than 3 wraps which ensures both material savings due to bad strip conditions and a good concentricity during recoiling at any speed.
Air is entrained generally if the tension is too low, large diameter rolls are used and line speeds are rising. The air thickness is a function of coil diameter, speed and tension. Nowadays, speeds in slitting lines for copper are not yet as high as in trimming lines or rolling mills for aluminium. Nonetheless, we expect the line speed to increase in the future which will turn our attention to the problem again. Solutions are available form other lines in operation such as to keep short distances between braking system and recoiling point. Furthermore, so called ironing rolls that apply a certain pressure to the coil O.D. before rewinding may be used. Here, a contact pressure of around 1.5 N/mm² is common. Care has to be given to the surface of the roll to prevent scratches to the coil. Also, the burr at the strip edge can have an influence (or at least support air to be entered). At this point, we can also see the influence of good slitting shear technology at the rewinding procedure.
Different tension within one coil is applied if the process is stopped or bigger changes in line speed are happening. A certain amount of this tension deviation can be prevented by adjusting the tension in the braking system (if the system design allows). But a complete stop will normally lead to a "step" or "shadow" at the coil edge. Another kind of different tension happens if the rolling profile of the entering strip is quite extensive and – after cutting – the single slit strips are tensioned before being rewound. Depending on the tensioning (braking) system, a different tension would result and thus at a certain diameter of finished coil some coils (typically at the outer sides) would be quite loose and the middle coils quite tightly wound (and in worst cases even plastically deformed). The modern braking means described before can prevent this as well.

Summary

Both the equipment manufacturer and the end-user of the equipment strive to be market leaders. The market wants cost-efficient solutions with high reliability, best possible product features (tolerances, surface quality, burr height, etc.) as well as economic production.
Close cooperation between plant supplier and end-user, starting in the project phase up to the daily operation ensures best planning, optimized plant layout and performance, good after-sales service and finally optimization of the production process. Therefore, the initial needs of the line operators have to be observed, and the applications of the final strip in subsequent industries (food, electronics, automotive, decoration, etc.) must be taken into account.
Thanks to the high level design of mechanical components acting together with the automation and control systems, repeatable set up of the slitting unit will make the operators work much easier. "Recipes" for the cutting programs can be entered into the system and recalled when applicable. The data base for these recipes is expandable as new strip dimension-property combinations will no doubt come along in the future.
As a result, the line composition has to be considered very carefully. Even though investment costs shall be optimized in the beginning, the life-cycle costs of the machines and the marketability of finished material (sheets, strips) must be the key factor for investment decisions. Danieli Fröhling's solutions can help the end-users of its technologies to open new market segments in a competitive way.