ABSTRACT
Recent testing has proven that the superior mechanical properties of INSULutions® STRIP-Flex K paper from Weidmann, when used together with Tuboly-Astronic’s advanced HV strip insulation winding machines, can produce more compact distribution transformer coils at faster speeds than with standard papers on standard winding machines. The high strength and high elongation of INSULutions® STRIP-Flex K allows HV strip insulation winding machines to operate with much higher paper tension, resulting in more compact coils. Compact coils are smaller, lighter, more cost effective and have lower losses. In addition, the machines may be run at much higher speeds and with less interruptions due to fewer insulation breaks, allowing users to increase productivity.

KEYWORDS
cellulose, insulation, high strength, strip winding, distribution transformer coils

INSULutions® STRIP-Flex K
Technology for efficient distribution transformer coils

Construction of liquid filled distribution transformer coils
Today’s liquid filled power and distribution transformers utilize the “industry proven” insulation system of cellulose-based solid insulation materials immersed in mineral oil. This system is recognized to be the most cost effective and reliable option for these applications. Weidmann has pioneered the development of specialized cellulose insulation materials, components and systems for transformers starting in the 1920s and has become the
per wire, wound in layers with interlayer insulation paper between the layers of wire.

HV winding interlayer insulation paper can be applied in different ways, and is usually dependent on the type of HV winding machine being used. In traditional winding machines, the HV interlayer insulation is applied manually between layers, usually as one or two layers of paper that are often the full width of the coil (Fig. 1). In this traditional process, the paper is not wound under tension, and there is limited or no opportunity to vary the thickness of the HV interlayer insulation across the layer. Varying the thickness of the HV interlayer insulation paper is desirable because the electrical potential difference changes across the layer, and changing the insulation thickness accordingly affords the chance for insulation optimization.

Disadvantages of traditional winding machines and technologies include:
- Less automation during the winding process
- Many stops for manual intervention
- Large scale and expensive inventory for many different insulation material widths
- Longer set up time
- More insulation material waste from paper roll "leftovers" due to slitting operations
- Less compact coil with lower filling factor
- Long winding times and lower winding productivity

Modern high voltage strip insulation winding machines from Tuboly-Astronic

Modern HV winding machines offer the chance to wind the HV interlayer insulation paper under tension, which helps the coil to be more compact. In addition, modern HV winding machines offer the chance to vary the thickness of the HV interlayer insulation paper across the layer, which is sometimes referred to as "graded insulation".

A common type of such modern HV winding machine is called a HV strip insulation winding machine, as in the models produced by Tuboly-Astronic (Fig. 2). In these machines, the HV interlayer insulation paper is wound in one or two narrow strips, ahead of and in parallel with the conductor wire. In addition, end

Weidmann INSULutions® STRIP-Flex K is a special cellulose insulation paper with high strength and high elongation properties, custom-designed for optimized use on modern HV strip insulation winding machines.
Modern HV winding machines, such as those from Tuboly-Astronic, offer the chance to vary the thickness of the HV interlayer insulation paper across the layer—sometimes referred to as “graded insulation.”

In order to operate HV strip insulation winding machines at the highest possible speeds, to maximize productivity with fewer paper breaks, and with the highest possible tension on the paper, to enable compact and efficient coils, a special cellulose paper with properties custom-designed for these machines would enable such benefits. Weidmann custom engineered such a paper, called INSULutions® STRIP-Flex K.

**Introducing INSULutions® STRIP-Flex K insulating paper**

INSULutions® STRIP-Flex K is a thin diamond-pattern coated layer insulation paper with 5 to 10% machine Direction (MD) elongation that provides superior performance for HV strip layer insulation in distribution transformers. Developed by Weidmann engineers specifically for use on modern HV strip winding machines, INSULutions® STRIP-Flex K gives distribution transformer manufacturers an unparalleled level of winding performance and the ability to run at high speeds and high tension, in order to produce compact coils with maximum winding productivity (Fig. 5).

The following features of INSULutions® STRIP-Flex K allow for such higher performance on HV strip insulation winding machines:

- High level (5 - 10%) MD elongation
- Superior tensile strength
- High winding “toughness”, i.e. Tensile Energy Absorption (TEA)
- Improved cross direction (CD) tear resistance
INSULutions® STRIP-Flex K also has the following additional features:

- Thermally upgraded, therefore having a higher thermal class than standard kraft cellulose papers (120 °C vs. 105 °C)
- Epoxy resin diamond dot coated, for superior coil short circuit strength
- Proven technology that is used successfully in regular production on high-speed modern HV strip insulation winding machines across the globe
- Applied as a simple and direct substitution for existing standard papers (at equivalent thickness)
  - Enhanced mechanical properties, but with same other properties
  - No engineering design changes required
- Although ideal for narrow HV strip insulation papers, can also be used in full width applications
  - No need to buy different grades of same thickness
  - The superior winding performance is offered at a price similar to standard papers
- Available in five different thicknesses:
  - 0.045 mm, 0.060 mm, 0.076 mm, 0.100 mm, and 0.125 mm
  - All are in production and available for evaluation

The recent testing performed at Tuboly-Astronic demonstrated that INSULutions® STRIP-Flex K on a type WHCF 450 machine can withstand a paper tension level up to and including the machine maximum of 60 N without breaking (Fig. 7).

When testing was performed on a Tuboly-Astronic HV strip insulation winding machine type WHDF 1000, in which two paper strips are wound in parallel, INSULutions® STRIP-Flex K was demonstrated to operate successfully at the machine maximum paper tension of 100 N without breaking.

This new approach – winding with a higher paper tension – leads to a more compact coil. Furthermore, with higher paper tension, there are fewer disruptions in the winding process with a more accurate graded insulation being achieved, due to the insulation being overlapped more precisely.

**Overall benefits of INSULutions® STRIP-Flex K insulating paper and Tuboly-Astronic HV strip winding machines for the distribution transformer manufacturer**

- **Optimized insulation design.** The thickness of the layer insulation is freely programmable from the start of the layer to the end, enabling optimized graded insulation. At the start of a layer, less overlapping results in thinner insulation thickness, while more overlapping at the end of the layer results in thicker insulation.
- **Compact coil.** Due to a high level of constantly adjusted strip insulation paper

**INSULutions® STRIP-Flex K is a thermally-upgraded thin diamond-pattern coated layer insulation paper with high MD elongation**

Recent tests completed using a variety of thicknesses and widths of INSULutions® STRIP-Flex K paper on different models of Tuboly-Astronic HV strip insulation winding machines, has proven the superior performance gains from using this combination of engineered paper and machine (Fig. 6).

Usually, a Tuboly-Astronic HV strip insulation winding machine type WHCF 450 is limited to operate at a paper tension level of approximately 30 to 40 N, due to the fact that standard papers tend to break beyond this level.

**Proven best performance –** INSULutions® STRIP-Flex K on Tuboly-Astronic HV strip winding machines

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A Tuboly-Astronic winding machine is limited to operate at a paper tension level of approximately 30 to 40 N, while INSULutions® STRIP-Flex K can withstand a tension up to and including 60 N without breaking.

- **Material savings - weight savings, cost savings and lower losses.** The optimized coil design with graded layer insulation, in combination with the higher strip insulation tension, results in an optimized radial build-up of the coil. This reduces the overall coil size which allows distribution transformer manufacturers to save on materials, not only in the coils themselves, but also with optimized cores as well. This results in overall distribution transformer weight savings, cost savings and lower losses.

- **Efficient, higher productivity.** HV strip insulation machines not only build up the layer insulation in a graded format, but they also build up the end wound coil becomes very compact.

**Figure 6. Recent testing of INSULutions® STRIP-Flex K paper on a Tuboly-Astronic HV strip insulation winding machine**

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filler strip insulation with the same strip. This efficiency eliminates manual intervention for building up the end filler strip. Also, the same paper strip at the end of each layer, passes under the conductor and builds up insulation in advance for the next layer automatically, avoiding the need for manual insertion of layer insulation at the start and stop of each layer. In addition, fewer paper breaks due to the high strength and high elongation of INSULutions® STRIP-Flex K help to further maximize productivity.

- **Flexibility and reduced insulation inventory.** Only a few different sizes of strip insulation paper (thickness and width) are needed to allow winding of all different coil designs. The preparation (slitting) and storage (space and costs) efforts to inventory many different full width insulation types can be avoided. In addition, there is very little waste of insulation material from slit-to-width operations or paper roll "leftovers."

**Conclusion**

The development of Weidmann’s INSULutions® STRIP-Flex K insulation paper fulfills the market need for a special cellulose paper with high strength and high elongation properties custom-designed for optimized use on modern HV strip insulation winding machines. This special paper allows these machines to operate with much higher paper tension, resulting in more compact coils. In addition, the machines may be run at much higher speeds and with less interruptions due to fewer insulation breaks. These features deliver to the distribution transformer manufacturer the benefits of smaller, lighter, more cost effective and lower loss coils, and efficient, faster and greater manufacturing productivity – all at a price similar to standard papers.

Advanced HV strip insulation winding machines from Tuboly-Astronic are designed to manufacture any and all different types of distribution transformer coils. Across the spectrum of coil designs and sizes, using one or two conductors, from small to big conductor cross section, Tuboly-Astronic offers different HV strip winding machine types that provide the greatest benefits when used together with new INSULutions® STRIP-Flex K insulation paper from Weidmann.

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