DJM : The steel future of dryer cylinders.

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The drying in the paper machine is the most energy-consuming process for a paper mill. It is therefore essential to invest to optimize the consumption of the drying section, which constitute a significant living cost for each paper mill.
In the past, drying cylinders were generally built in cast iron, a material that is easy to find and low cost, but above all easy to machine, which still allows an easy construction of the cylinders.

Currently, the demand for higher machine speeds and wider formats imposed by the market requires a proportional increase in the number of drying rolls to maintain the same level of drying capacity of the machine. The use of modern steels and modern manufacturing techniques have led to not making the use of cast iron cylinders more advantageous, the replacement of which can bring great benefits in terms of machine management, especially regarding energy saving.
In this short technical excursus we will try to demonstrate the reasons.

The factors that most influence the heat exchange through the drying cylinders are in fact:

- diameter, thickness and material of the cylinders;
- operating pressure and temperature;
- condensate drain system.

Given the limits on the maximum operating pressure, and on the maximum condensate that can be extracted from the cylinders with current technologies, it is logical to invest, to improve the efficiency of the drying in the replacement of the cast iron cylinders with steel cylinders.
The change from cast iron cylinders to steel in fact allows 4 fundamental advantages:

- greater thermal efficiency, since the thinning of the thickness of the cylinder shell leads to a significant increase in heat exchange; - greater useful drying surface, due to the enlargement of the working width consequent to the smaller size of the heads;
- faster reaching of the working temperature, given by the increased heat exchange;
- increase in safety standards, linked to the higher safety coefficients used for steel.

Heat exchange

A drying cylinder can theoretically be treated as a thin-wall pressure vessel ($s << 2R$). It is therefore possible to schematize the heat exchange between the steam and the sheet of paper with the simplified model schematized in figure 1 and based on the following hypotheses:

- the shell of the cylinder can be treated as a flat plate ($s << 2R$);
- the global heat transfer of the shell-paper also includes the transfer of heat through the thin layer of air between the shell and the sheet of paper

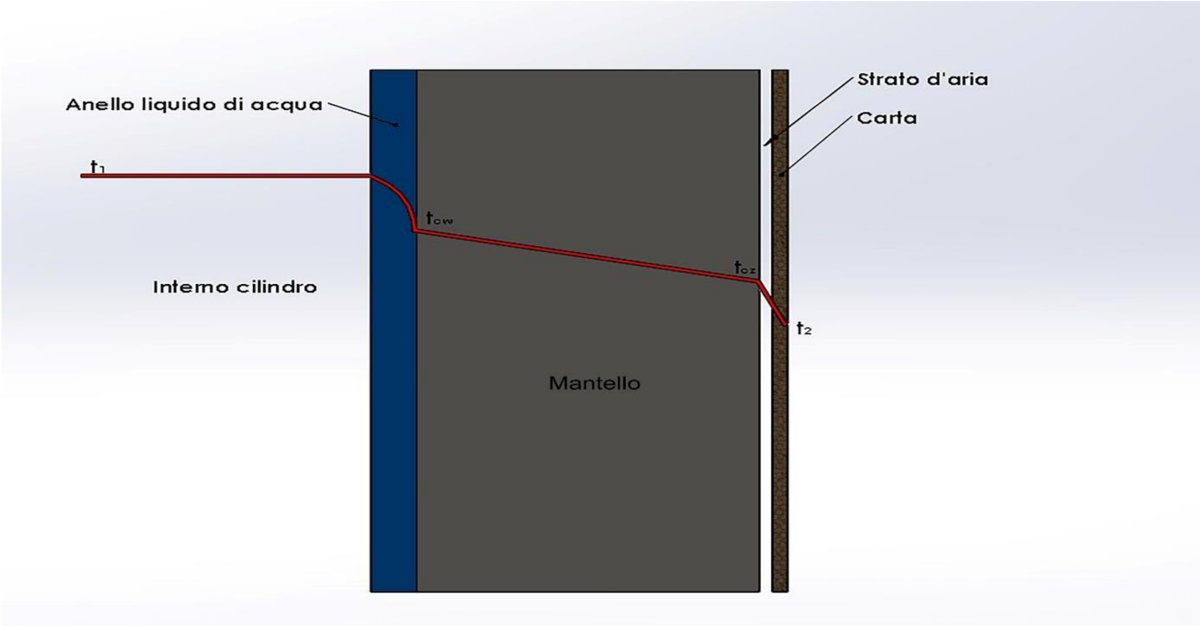

FIGURE 1: Qualitative trend of the temperature in the system.

Anello liquido acqua = Liquid water ring; Interno cilindro = cylinder internal; Carta= paper; strato aria = air layer; Mantello = shell

Therefore, starting from the previous hypotheses, the equation that represents the thermal flow affecting the surface of the cylinder is given by:

$$q = (\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2})(t_1 - t_2) \qquad (1)$$

Where :

q = thermal flow, W m-2;

t1 = steam temperature inside the cylinder, ° C;

t2 = external temperature of the sheet of paper, ° C;

α1 = steam thermal conductance - internal shell surface, W m-2 K-1;

s = wall thickness, m;

α2 = thermal conductance outer surface of the shellt - outer surface of the sheet of paper, W m-2 K-1;

λ = thermal conductivity of the shell, W m-1 K-1.

Assuming the value of the sum $\frac{1}{\alpha_1} + \frac{1}{\alpha_2}$ constant for both cast iron and steel cylinders and equal to $1{,}35 \cdot 10^{-3}$ m^2 K W^{-1}, the only parameter on which to act to vary the heat flow is the thickness of the drying cylinder shell, which must be sized according to the standards (ASME / UNI), that define the minimum thicknesses to be used.

In the following discussion we have chosen to use the UNI EN 13445-3: 2019 standard, which allows us to arrive at the following formulation of the thermal flow transmitted by the steam to the sheet of paper.

$$q = \frac{1}{\frac{1}{\alpha_1}+\frac{s}{\lambda}+\frac{1}{\alpha_2}}(t_1 - t_2) = \frac{1}{\frac{1}{\alpha_1}+\frac{\frac{pDe}{2(f/i)z+p}}{\lambda}+\frac{1}{\alpha_2}}(t_1 - t_2) \quad (2)$$

where:

p = steam pressure inside the cylinder, Pa;

De = outer diameter of the shell, m;

f = material yield stress, N / mm2;

i = safety factor, according to UNI EN 13445-3: 2019 adim .;

z = joint coefficient, according to UNI EN 13445-3: 2019, adim .;

From (2) it can be deduced that, for the same pressure and diameter of the cylinder, the heat exchange depends on λ and f, so, on the characteristics of the material used. The values of λ and f for steel P 275 NH and cast iron G25, used for the construction of drying cylinders, are shown in Table 1, from which it is evident that, even if practically with the same thermal characteristics, the best mechanical characteristics play in favor of steel compared to the improvement of the heat exchange.

Table 1 - values of λ and f for steel P 275 NH and cast iron G25

material	**λ** **[W m^{-1} K^{-1}]**	**f** **[N/mm^2]**
steel P 275 NH	49	275
Cast iron G25	46	110

Working Width

The second factor to consider when choosing the drying cylinders to be used in the drying section of the continuous machine is the maximum width. In fact, the paper market is shifting its trends towards ever wider formats, so that paper mills, in order to be competitive, must expand their format width. As we will see, the steel drying cylinders, with the same overall dimensions, have a much greater useful width, thus allowing a precious recovery of centimeters of format and an increase in the thermal energy transferred to the sheet of paper, without necessarily modifying the external structures of support.
Figure 2 shows the construction drawing of two drying cylinders, one in steel and one in cast iron. It is evident that compared to the heads of the cast iron cylinder, steel cylinder’s heads, thanks to the weldability of the material and the best mechanical characteristics, has smaller dimensions.

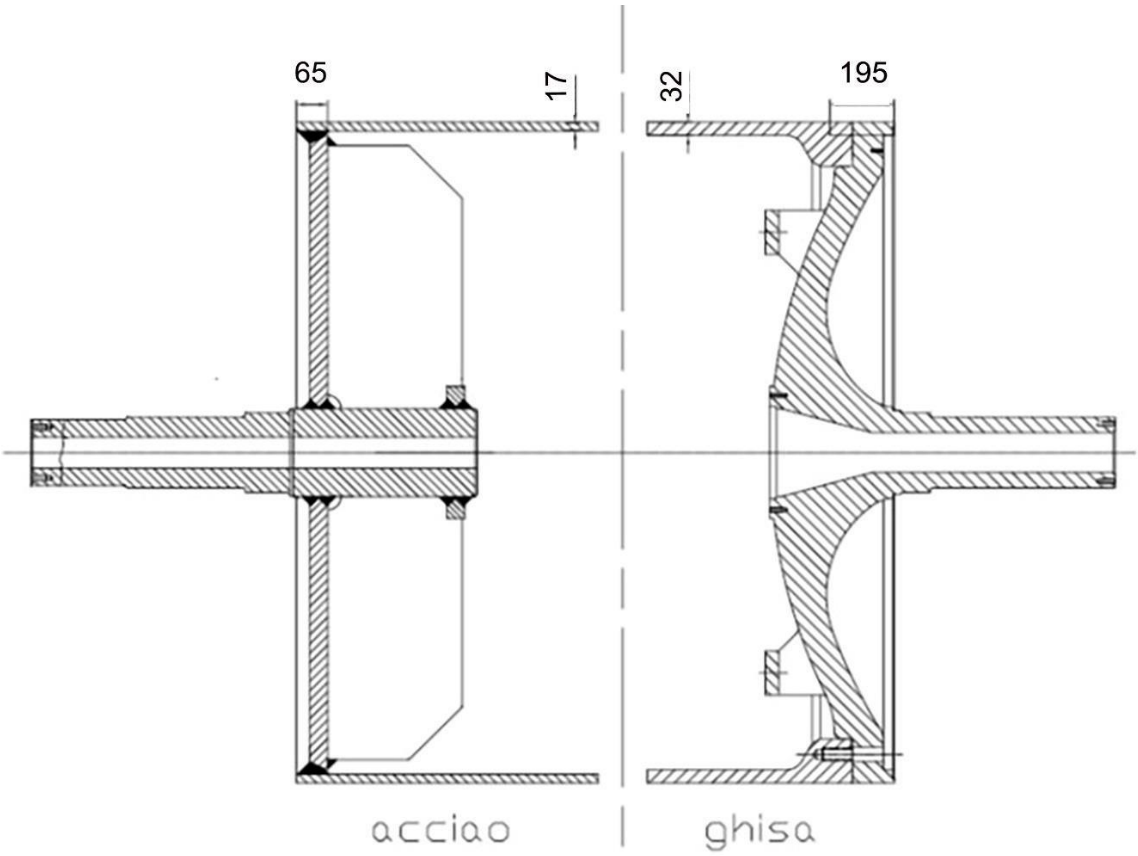

FIGURE 2: Construction drawing of steel (left) and cast iron (right) drying cylinders.

Furthermore, due to the different type of design and construction technique, in the case of the steel cylinder the shell maintains a constant thickness up to the head, which determines the temperature trend shown in Figures 3 and 4, with a uniform heat distribution in the shell up to the ends of the cylinder.

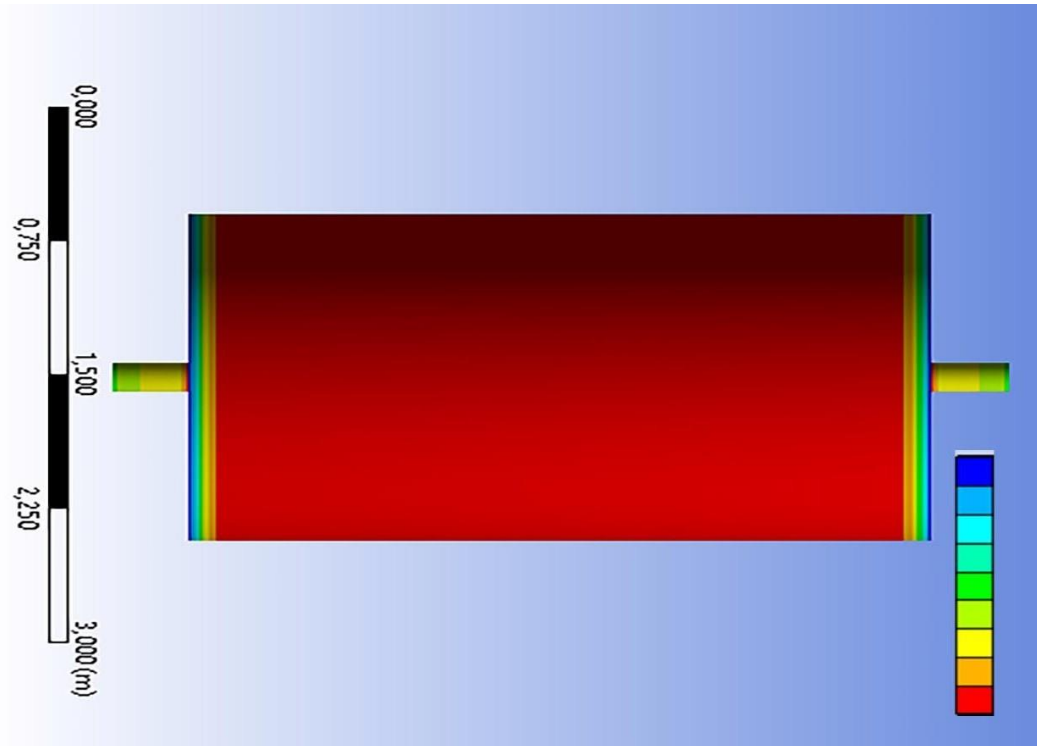

FIGURE 3: Trend of temperatures on the shell of the P275NH steel dryer cylinder.

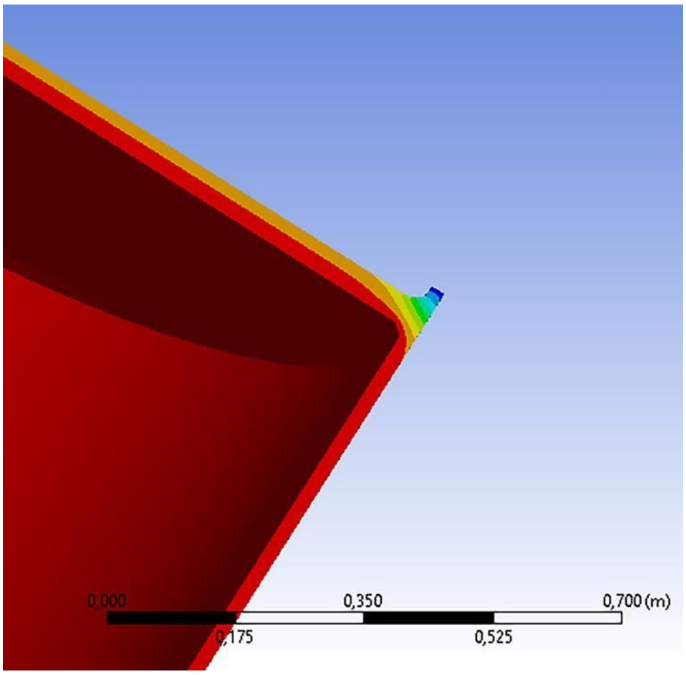

FIGURE 4: Trend of temperatures in the thickness of the P275NH steel dryer cylinder.

Figures 5 and 6 show that the cast iron cylinder, as mentioned, has the head slightly more recessed and it has a variation in thickness on the extreme sides of the shell.

For that reason the temperature trend is not uniform and not allows to obtain a pefect drying process of the sheet.

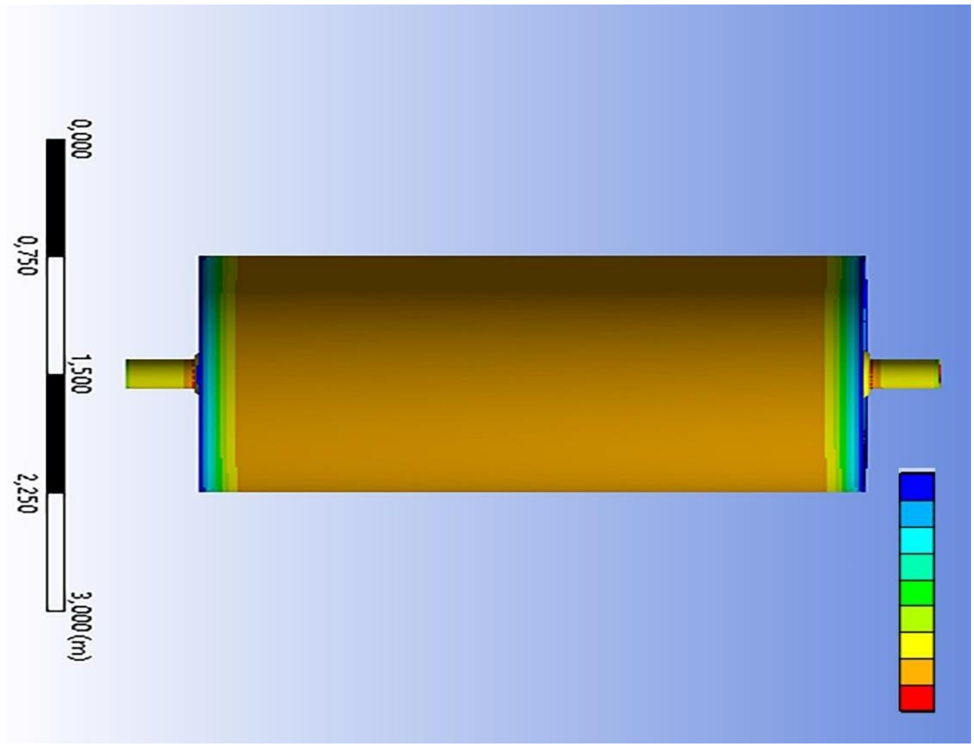

FIGURE 5: Trend of temperatures on the shell of the G25 cast iron dryer cylinder.

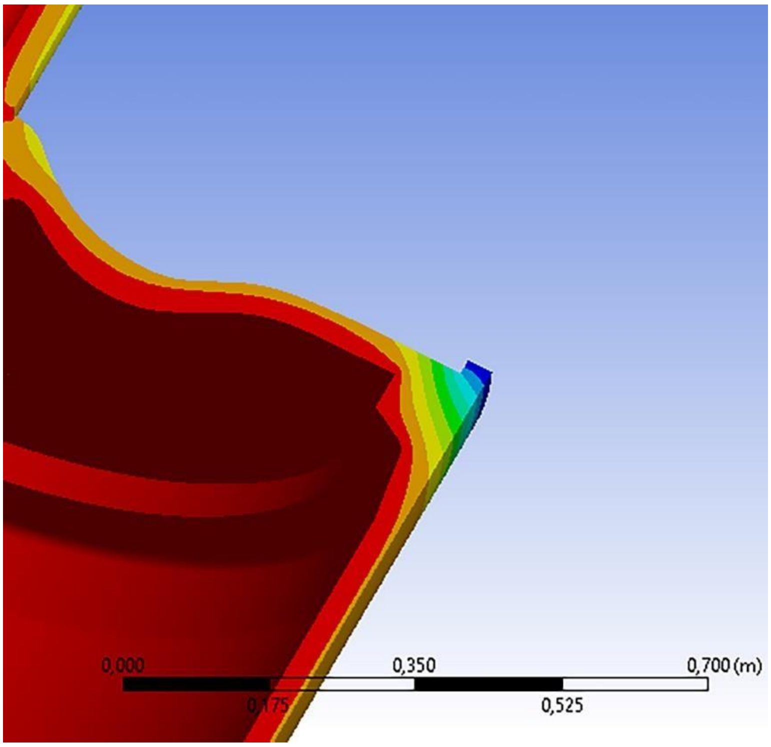

FIGURE 6: Trend of temperatures in the thickness of the G25 cast iron dryer cylinder.

From the point of view of geometry, using a steel instead of a cast iron cylinder, bring generally to an increase of about 130 mm of useful width per side, therefore 260 mm of width difference, simply because of the different construction design. All this means that, in addition to being able to use a larger format, there is less heat loss through the walls of the cylinder, with a general increase in efficiency.

Case study

Two possible models of dryer section are compared below, one with cast iron cylinders and the other with steel cylinders, to understand the advantages of the two different technologies. We start from the hypothesis of cylinders of the same diameter and the same operating pressure, therefore under the same working conditions, which are interchangeable with each other without modifications to the machine structures; the only variation will be due to the different thickness of the shell, linked to the different resistances of the two materials. The data relating to the two models are shown in Table 2.

Table 2 - Data relating to the two models of dryers considered

material	**Diameter [mm]**	**Shell thickness [mm]**	**Width [mm]**	**pressure [bar]**
steel P 275 NH	1500	17	2400	3
Cast iron G25	1500	32	2400	3

The useful drying area of the two cylinders are obtained with the relationship:

$$A = 2\pi r * (L - b) \quad (3)$$

where:
L = cylinder width, mm.
b = useful width reduction, mm.

From (3) therefore it results:

A_{P275NH}=12,98 m^2
A_{G25}= 9,42 m^2

Using the relationships (1) and (2), the transition to the steel cylinders in this case allows an increase in the useful drying area equal to 13%, with the important benefit of eliminating the problems of lateral humidity at the edges of the finished sheet. With reference to the heat exchange, considering the same values of the temperatures t1 and t2 of Figure 1, the passage to steel cylinders guarantees an increase equal to 18%, due to the lower thickness of the shell, while maintaining a higher safety coefficient. Considering the contribution due to the different characteristics of the materials and the widening of the useful table, the use of the steel cylinders increase the heat exchange by 33%, an increase that is immediately translated into a saving of the quantity of steam needed by the dryer, and therefore in less drying cylinders necessary to obtain the same performance obtainable with the cast iron cylinders.

A second type of analysis concerns the more drastic situation in which a paper mill intends to carry out a deeper upgrade of its own dryer, varying not only the material of the drying cylinders, but also their diameter and their operating pressure. The data relating to the cylinders and the operating pressure values at the pre and post intervention are shown in Table 3.

Table 3 - Data relating to the cylinders and the operating pressure values at the pre and post intervention dryers

material	Diameter [mm]	Shell thickness [mm]	Width [mm]	pressure [bar]
steel P 275 NH	1830	20	2400	10
Cast iron G25	1500	32	2400	3

In the first analysis it is clear that the larger diameter and the larger useful width of the steel cylinders entail a much higher drying surface, which can be calculated with (3) and is equal to 38%. In view of this, the steel shell, while maintaining a high safety coefficient, will have a smaller thickness than the cast iron shell, and this will generate an increase in the steam-paper heat exchange equal to 14% in advantage of steel. Ultimately, the heat exchange obtainable with the steel cylinder is 57% greater than the one that occurs with the homologous cast iron cylinder. Obviously, the basic hypothesis is that the temperature difference between the inside of the hood and the steam introduced into the cylinder is the same for the two types of cylinder.

Conclusions

The transition from cast iron to steel cylinders appears to be a winning choice for all paper mills that want to modernize their buckets and improve their efficiency by reducing their management costs. Of course, the increase in efficiency from the point of view of heat exchange does not correspond to a proportional increase in the water extracted from the paper, which also depends on other physical factors not treated in this review. In any case, already from this first partial analysis, the advantages linked to the use of steel in dryers emerge, and that will certainly represent the future of all paper mills.

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