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DESIGN AND OPTIMIZATION OF MECHANICAL SOLUTIONS FOR HIGH SPEED COMPONENTS IN PACKAGING MACHINES

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Abstract: *Abstract: The paper presents the results of a study on optimization of mechanical solutions focused on a vertical stretch wrapping machine. The calculations made by using simulations are according with all analytical evaluations.*
Key words: *Packaging, Metal Matrix Composite Materials, ANSYS WB, non linearity*

INTRODUCTION

In the 1980's a small artisan company starts to produces robot for packaging, equipped with rechargeable batteries and a feeler, which turned autonomously around pallets of any size, applying stretch film to stabilize the load. This innovative idea was later patented and widespread all over the world. Soon the company became well known as a world leader in semi–automatic machines for the application of stretch film for stabilizing pallet loads, developing a number of other machines to join the robot including: rotating tables, horizontal wrapping machines for elongated products, a ranges of shrink film packaging machines and taping machines. These automatic systems and machines are able to stabilize pallet loads with stretch film capable of catering for up to 100 pallets per hour, thanks to a range of high-tech solutions with excellent levels of productivity.

The commercial success for every packaging machine is directly related to a correct balance between costs of equipments (as low as we can) and efficiency in processes (as high as it is possible). Regarding this second aspect, during the last years, the sector noticed a progression of technical solutions toward faster and faster machines. From an engineering point of view, one of the simplest way to speed up a machine is to take particular care to reduce inertial masses. This result can be obtaining modifying geometry or changing the material.

This study is focused on the redesign and the optimisation of a *pretension roller* for the stretching of elastic film and the deposition on pallet. The pretension roller is a fundamental component inside the semi-automatic packaging machine permitting, coupled with other rollers, to accurately calibrate the ratio of stretching for the elastic film (reducing wastes of film), but also the wrapping up pressure on the pack (assuring the stability of pallet and the integrity of goods during the packaging process).

Linear and non linear FEM analysis were used together with a theoretical modelling of physical conditions for the pretension roller. The hypothesis to substitute steel with aluminium was considered and accepted. A reduction in thinness and new solutions to guarantee the same level of friction on surface were taken in count.

COMPONENT INSIDE THE MACHINE

The study is focused on a *vertical stretch wrapping machine*. In this configuration the pretension roller represents an important and critical component for the packaging machine, with a strong impact on the entire system.

Assembled on a mobile unit, every problem to the pretension roller can provoke an unstable working condition for the machine.

Fig. 1: A vertical stretch wrapping machine

The machine contains two rollers (fig. 2) which, revolving with two different angular velocities, create the stretching forces on the film. In this way an elasto-plastic deformation of 300% is realized on the film. By this extension, it is possible to reach several results:

- a minor length of film is used for packaging the pallet reducing costs, but also limiting wastes of materials with a beneficial impact on the environmental aspects of the process;
- a proper level of pressure and compressive forces on the pallet is created, able to stabilize it permitting a safer transportation and a protected storing.

Fig. 2: System of pretension rollers

The pretension roller is realized by steel metal sheets, with a thickness of 3mm able to assure an appropriate stiffness. A layer of vulcanized rubber is deposed on surface to obtain a friction able to drag and stretch the film.

Roller's weight becomes relevant especially in transient conditions and provoke an over-dimensioning of the whole frame with an inefficiency in the dynamic of the machine.

AN HYPOTHESIS OF USE OF NEW MATERIALS

A reduction in weigh can be obtained using lighter materials (as aluminum or others). In DIEM – University of Bologna, several Metal Matrix Composite Materials (MMCMs) are under investigation for their high mechanical performances, especially the family of composite materials with aluminum matrix and ceramic inserts for their lightening and high resistance to wearing. MMCMs also present several disadvantages as high ductility, high toughness and difficulty in working with normal burr cutter

Anyway, MMCMs already represent a valid engineering solution in several industrial applications, but, since the high costs for production and manufacturing (for example, they need specific tools and advanced tool machines), at the current state, their diffusion is limited to few borderline applications, especially in transportation (as brakes in high-speed trains).

Our progress beyond the state-of-art is related to the research idea to use a different process for production of MMCMs. At the Laboratory for Innovative Materials in Mechanical Design (MATMEC) of the University of Bologna, a metal casting process involving MMCMs has been established in its fundamental parts. Some prototypal casts in MMCM are now available and the use of MMCM for ordinary industrial applications represents the next challenge.

This paper proposes a first conceptual application of MMCM to the case of a packaging machine. Passing by theoretical and FEM validation, we propose a change in materials for a fundamental part of the automatic plant. In some aspect of calculation, MMCMs' mechanical behavior are approximate with aluminum's parameters since the main differences are related to friction coefficient and wearing progression.

Fig. 3: Metal casting of MMCMs

CONCEPTS OF DESIGN REVIEW

Substituting steel (7.8 kg/dm^3) with a lower density material, as MMCM or also aluminum (2.8 kg/dm^3) is going to offer lighter components and a better dynamic response of machine. But, at the same time, it is necessary to take in count of the differences in the mechanical resistance for materials (the yield stress for aluminum is 130 MPa much less than 200-400 MPa for steel).

Then, instead of a simple changing in constructive materials, a massive reduction of weight can be obtained only directly modifying the geometry and, if possible, the principles of functioning for components, to make the most of the properties of MMCMs. Specifically:

1. if new design solutions are able to assure a suitable rigidity, the pretension roller can be also realized with a reduction in thinness. Considering designers have never evaluated which is the proper rigidity for the correct functionality of this component (paying attention to increase rigidity "as much as possible"), an exact calculation of deformation under loads can even discover the possibility to reduce thinness and weight;
2. if a contact surface made of MMCMs is able to assure a proper friction coefficient to drag and deform the film in the right way, it is possible to avoid the additional layer of vulcanized rubber (reducing costs). At the same time, the current problems of progressive wearing for rubber are totally solved.

THEORETICAL APPROACH

The behavior of the structure under working conditions were firstly investigated with a theoretical approach by the following steps:

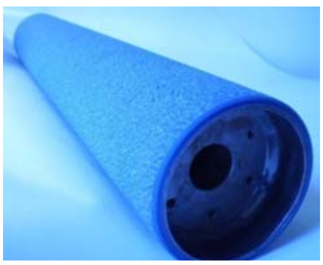

Fig. 4: The pretension roller

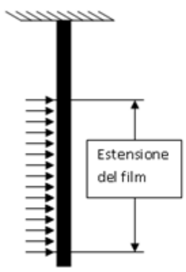

Fig. 5: Model of cantilevered beam

♦ *Preliminary analysis of functionality*

For a theoretical analysis of pretension roller, the system could be represented by a cantilevered beam (fig. 4 and 5). Boundary and load conditions for roller could be simplified considering a fixed boundary on the supporting surface and a equally distributed load on a segment of the beam (corresponding with the contact area for the film).

Moreover, referring to the standard modeling of a pulley (see in fig. 6) and the related equations, force F_2 appears rather negligible respect to F_1: considering the high coefficient of friction for the vulcanized rubber, F_1 is totally balanced by friction forces and all equations are simplified.

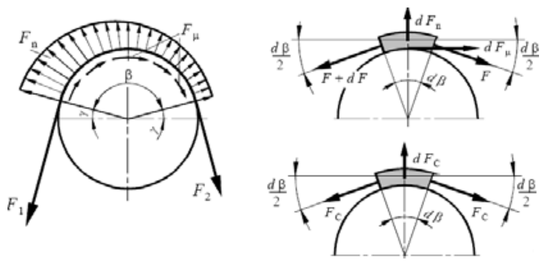

Fig. 6: Distribution of forces on a pulley

♦ *Evaluation of forces and loads*

According with the previous simplifications, the force F_1 can be easily estimated considering the state of deformation for the film. Under the F_1 normal force, a 0,3 μm thickness film of 60mm large, presents 300% elasto-plastic elongation; considering the stress-strain curve for this specific material, polyethylene (fig. 7), a 500N force is evaluated as limit.

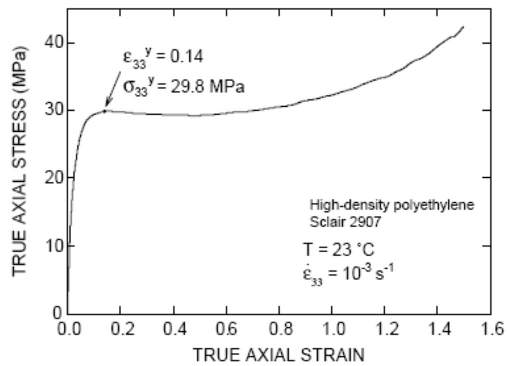

Fig. 7: Tensile behavior of the polyethylene

Regarding the friction (known as total force, but unknown as distribution), the contact angle depends on the specific geometrical configuration of machine (for example on the relative position between rollers), but its range is commonly between 90° and 180°. The analysis was repeated using both values obtaining limits in the variability of results.

By geometrical considerations and density of material, the weight (about 3.2kg for steel and 2.5kg for aluminum with the same shape) was estimated. Centrifugal forces (about 460N) were evaluated by eq. (1)

(1) $$F_C = 10^{-6} A \rho V^2$$

With F_C - centrifugal force
A - cross section area of pulley
ρ - density
V - angular speed

♦ *Standard dimensioning*

Two different structures of roller were analyzed:

1. a "sandwich" made of steel (6mm of thickness) and rubber (8mm thickness)
2. a "solid" of MCMM (6mm of thickness)

In the case of "sandwich", modulus of elasticity can be calculated by

(2) $$E_{ekv} \cdot I_{tot} = E_1 I_1 + E_2 I_2$$

E_{ekv} - Equivalent modulus of elasticity
I_{tot} - Total moment of inertia
E_1 - Young modulus for steel
E_2 - Young modulus for rubber
I_1 - Moment of inertia of tubular profile profile made of steel
I_2 - Moment of inertia for a tubular profile made of rubber

By similar considerations, a complete theoretical evaluation of pretension roller were realized.

Material proprieties and basic results for the theoretical calculation are available in fig. 8

			Steel and rubber		MCMM (aluminium)
Density		Kg/mc	7'850	720	2'770
Moment of Inertia		Mm4	530'000	930'000	1'500'000
Yield stress		MPa	900-1'200		100-120
Thickness		mm	6	8	14
Film pressure (polyethylene)		N	500		500
Weight of roller		Kg	3.2		2.5
	Mflexure	Nm	123		123
	Mtorion	Nm	20		22
	σ_{max}	Mpa	3.6		3.7
	η_{max}	Mm	0.06		0.07

Fig. 8: Main parameters and results for the theoretical evaluations

USING FINITE ELEMENTS

Next step for redesign passed by the numerical simulations thanks to the "Smart Engineering Solver" of Ansys Workbench v.12.

Fig. 9 : Input windows for Ansys WB

Once pretension roller was designed in CAD environment of SolidAge, geometry was exported to Ansys WB. Volumes were discretized by finite elements. As material characteristics steel, rubber or aluminum were inserted according to each specific simulation for comparison. Several conditions for loads and boundaries were investigated. Von Mises stresses and relative deformations were observed highlighting the critical zones.

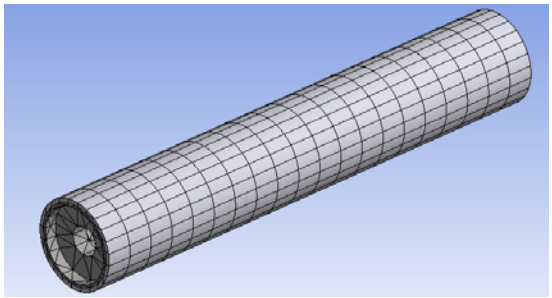

Fig. 10: Meshing for the roller

LINEARITY IN SIMULATIONS

In the case of a pretension roller made by "solid" MCMM (or aluminum) material, simulations calculation could be performed without particular difficulties since the problem is linear. FEM results were compared with analytical estimations in several cases under investigation.

On the opposite, for the "old" roller, made by a "sandwich" of materials, a non linearity occurs.

In general, non linear analysis is requests if the model presents nonlinearity in:

- the geometry, as in the case of large displacements, angles, deformations or their combinations;
- the behavior of materials. Rubber and hyper-elastic materials (as polyethylene) are

typical examples of non linearity in materials. A non linear behavior is related to some unusual aspects as the fact that the relation between stress and deformation depends on the number of cycles of loads, on the speed of application of loads and, even, on the temperature

- the contact when boundary conditions change since the application of loads.

During our simulations, the models were subjected not only to nonlinearity in materials (polyethylene and vulcanized rubber), but also nonlinearity in contact (between rubber and steel) with changes of contact areas under the pressure of film, and even large displacement in the film.
Regarding the large distortion of polyethylene, plastic deformation of materials has to be treated with particular attention. In this case, it was necessary to choose with care the type of contact for each contact surface; the contact between steel and rubber was defined as "bonded". Moreover exact strain-stress curve for non linear material as rubber and polyethylene (Fig. 7) were inserted as input. Large displacements were taken in consideration activating the solver for "large deflection" in a time-consuming process.
Some results as stress and strain distributions are reported (fig. 11, fig. 12) and they are according with all the analytical evaluations

REFERENCES:

[1]. T.W. Clyne, An introduction to metal matrix composites, Cambridge Press (1993).

[2]. Composite Materials Handbook. Volume 4. Metal Matrix Composites. MIL-HDBK-17-4. Sept. 1999

[3]. M. Taya, R.J. Arsenault, Metal Matrix Composites - Thermomechanical behaviour, Pergamon Press, (1989).

[4]. J.W. Kaczmar, K. Pietrzak, W. Wlosinski, "The production and application of metal matrix composite materials", Jo. Mat. Proc. Techn. 2000

[5]. M.D.Huda, M.S.J. Hasmi, M.A. El-Baradie, MMCs: "Materials, Manufacturing and Mechanical Properties", Key Eng. Mat., 1995

[6]. J.Eliasson, R. Sandstrom: "Applications of Al Matrix Composites", Key Eng. Mat., 1995

[7]. ANSYS, User 's manual (version 11 and 12), ANSYS Inc., 2009

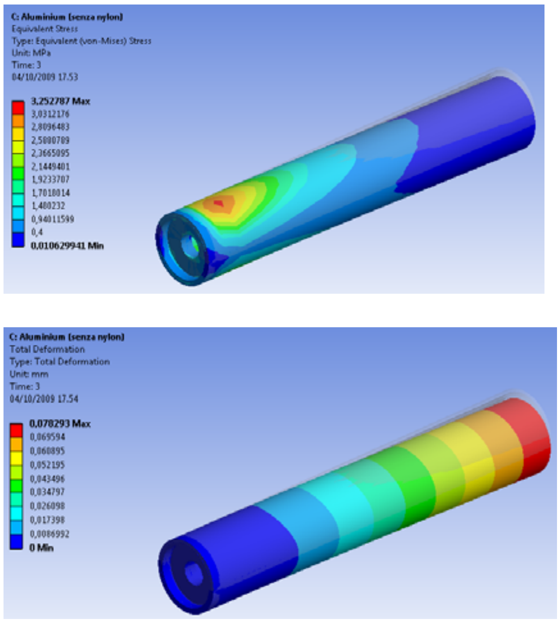

Fig. 11: Stress/deformation for MMCM roller

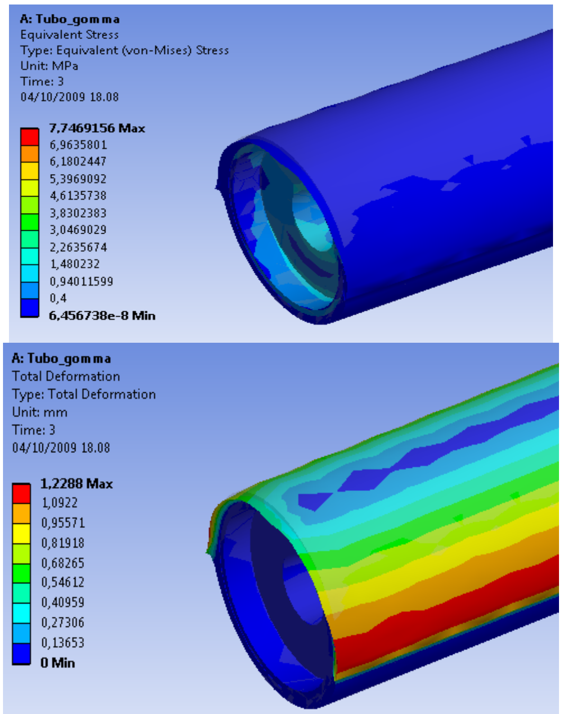

Fig. 12: Stress and deformation for a sandwich" of steel and rubber under the pressure of film

[8]. M.Kojic, R. Slavkovic, M. Zivkovic, N. Grujovic: "Finite element method - nonlinear analysis", faculty of mechanical Engineering in Kragujevac, University of Kragujevac, Kragujevac, SCG, 1998

[9]. F.Addiegio, A.Dahoun, C.G'Sell, J.M.Hiver "Characterization of volume strain at large deformation under uniaxial tension in high-density polyethylene", Science Direct, may 2006

ПРОЕКТИРАНЕ И ОПТИМИЗАЦИРАНЕ НА РЕШЕНИЯ НА МЕХАНИКАТА ЗА ВИСОКОСКОРОСТНИ КОМПОНЕНТИ НА МАШИНА ЗА ПАКЕТИРАНЕ

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ИТАЛИЯ

Ключови думи: *пакетиране, композитни материали с метална решетка, ANSYS WB, нелинейност.*

Резюме*: Докладът представя резултатите от изследване върху оптимизацията на решения от гледна точка на механиката, насочени към пакетираща машина с вертикално разтягане. Изчисленията, направени чрез използване на симулиране, са в съответствие с всички аналитични оценки.*