Testing methods and equipment for palletized products

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Abstract. The ability to present cutting-edge solutions for packaging in the field of palletized products has to be considered as the result of the investments in research infrastructures and advances in applied researches. In the present article, main equipment and all the other testing facilities used to optimize palletized product are detailed. Tests are implemented in accordance with standard and no standard procedures up to fully innovative methods. This approach is able to provide advice both on the most appropriate palletizing scheme to pack the load, either on the best packaging methods able to conserve intact the product to the consumer. For customer it represents a great added value that allows to experience first-hand palletizing solutions, packaging and stability of the load, reducing production costs and optimizing efficiency.

1. Introduction

Over the years, the packaging industry has become increasingly important. At the beginning, the essential aspect was to guarantee a safe, functional and aesthetically appreciated product packaging. Later, and rather recently, the packaging has covered additional aspects such as environmental sustainability of transport and the integrity of the goods transported (as in [1]). In this regard it is usual to differentiate a 'primary packaging', the one intended to contain the product in contact with it (e.g. bottles, blisters, etc.), from a 'secondary packaging', used to collect and protect the goods during transport (e.g. [2]). For this second form of packaging it is common to group primary containers (e.g. bottles, blisters, etc.) in bundles, consolidated through heat-shrink material, and then in pallets [3]. These pallets are wrapped in prestressed films of plastic material that stabilize the package [4].

This secondary packaging process is characterized by a significant number of parameters, such as, for example, the type and thickness of the film, the number of layers, the strength of pre-stress and so on. This ‘recipe’ should be optimized in consideration of the type of product to be packaged (geometry and materials, e.g. glass bottles vs cardboard boxes) as well as the type of transport envisaged (e.g. distance, means of transport, time and place of storage) (as done in [5]). Only thanks to such an approach toward the optimization, it would be possible to guarantee an efficient packaging and a competitive product, fully in line with an approach oriented to the Total Quality Management [6]. Otherwise, the risks are of various types: from the waste of plastic film for an oversized packaging to damage to the product due to insufficient packaging. The related effects are not only of an economic nature, but also of safety (e.g. unforeseen fall of goods), and of environmental sustainability due to the waste of material and energy in the case of unusability of the product.

At the same time it is not at all easy to arrive at the determination and best packaging conditions as it is not always clear how each of the process parameters impact on the final packaging. Furthermore, the loads (mechanical, environmental, etc.) to which a package must withstand are not always known.
There are numerous studies that attempt to clarify both the aforementioned aspects in order to identify the most suitable package for each planned journey. Transport by ship [7], by train [8], by truck [9] are just some of the different options that identify the specific load spectra to which a package is subjected during transport. In the various studies the attempt is to categorize these solicitations around some bases of reference, such as, for example, the geographical area (e.g. Europe [10], America [11], Asia [12-14]) or the type of route travelled (highway vs secondary roads [15, 16]). This is joined by all that is present although less intuitive. This relates, for example, to secondary handling (e.g. inside the depots, in the ports [17], in the loading and unloading phases [18]), including shocks (expected or not) [19, 20], storage inside or outdoors (changes in temperature, humidity [21] and irradiation with modification of the properties of the film.

This problem is so worthy of attention that innumerable standards have arisen. Among many of others it is interesting to mention: EUMOS 40509 for evaluating the load unit rigidity [22]; the ASTM D4003 as test method for horizontal impacts of containers [23]; ASTM D5276 for drop tests on containers [24]; the ISTA list on procedures for simulating the effect of different mean of transportations [25,26].

2. Aims and Scope
Regardless of the characteristics of the packaging considered to be the most suitable [27] and the stresses expected during the trip or their theoretical models (as in [28]), there will always be a time when all these considerations must be tested through an experimental approach.

In other words, we will always need a laboratory equipped to test packages. This goal is not obvious in terms of feasibility, especially considering how the packaging subject to analysis can be very large and heavy, and must be subjected to rather significant impulsive loads, capable of reproducing stresses similar to those present during transport, including events such as shock (as done in [29]).

Some regulations help simplifying real loads by considering them equivalent or less burdensome than those provided through standard tests. Several studies and even our experience suggest that these tests are not to be considered equivalent, nor more rigorous [30, 31].

Globalized transport, multimodality, speed, the quantity of goods around and the many other conditions present in a modern business toward a flexible manufacturing system [32, 33], let us believe that standard tests are rather a basis from which to start.

In short, a pallet must pass these tests undamaged, but this is not a sufficient condition to ensure that packaging is adequate for real. The perfect test equipment would be that able to solicit the pack with loading profiles similar to those found in the field (e.g. through experimental measurements).

This study describes our testing laboratory for palletized pallets through the description of the two testing machines, traditionally used for performing standard tests. In particular, it is possible to state that the two most used and effective ways to test the products that are packaged by means of the wrapping machines are the vibration platforms and the acceleration sledge.

Added to the, the study reports the description of a new testing machine, specifically designed and equipped to provide loads to pallets with a view to maximum experimental flexibility [34]. It consists of a commercial hexapod platform, with 6 degree of freedom (DoF), powered by a specific control system and a special loading platform, able to strictly fix the pallet during the test.

3. Vibrating platform
This platform is used to verify the stabilization effectiveness of the palletized load by vibrating the table at a configurable frequency (figure 1). The machine was developed to verify that these standards are satisfied: ASTM D5415-D5495 ruling standard test method for evaluating load containment performance of stretch wrap films by vibration testing [35]; ISO 2247 on Packaging complete filled transport packages and unit loads. Vibration tests at fixed low frequency [36].

The platform presents a rigid part, the basement, that is leaning on the ground through four feet. This part makes a rigid body able to bear the inertial stresses induced by the vibrating plane (as in [37]), faithfully providing a test setup that reproduces this harmful mechanism for the merchandise [38-39].
The operation principle of this platform is based on the rotation of two eccentric shafts with horizontal axis, moved by an asynchronous motor, that connect the moving part with the fixed one. The resulting components of the uniform circular motion are oscillatory harmonic with fixed amplitude and frequency proportional to motor speed.

![Image of vibrating platform](image1.png)

**Figure 1.** Vibrating platform.

![Graph acceleration-frequency (ISO 2247)](image2.png)

**Figure 2.** Graph acceleration-frequency (ISO 2247)

The test indicated in the standards consists of a table vibration at a fixed acceleration (g) for a certain period of time (10 min according to ASTM) and looking for load movements, wrapping material tearing or splitting, or other load integrity losses. If the load withstands to this test, it must be repeated at a higher frequency. Since the vertical displacement of the table is fixed, the relation between acceleration and frequency can be seen in figure 2 where \( \gamma(g) \) is the peak of acceleration, expressed in terms of acceleration due to the gravity \( g \); \( a \) is the peak amplitude, expressed in millimetres (shifting in the diagram from 10 to 25 mm); \( f \) is the frequency, expressed in herz.

The displacement of the platform is fixed at 25 mm, so the correct line that connects acceleration to frequency must be followed. It is really helpful to know the vibration frequency of the load because every type of product has an own natural frequency and it can be seen resonant behavior also at very low frequency (0-5 Hertz range).

In figure 3, it can be seen, as example, the results of a test performed on the vibrating platform at 2.5 Hertz for 10 minutes, on a palletized load wrapped with a specific program, reported in Table 1. The related wrapping program consisted in that case of 25 revolutions on film, characterized by \( \sim 340g \) of weight, and a medium pre-stretch of 260%.
4. Acceleration sledge

The acceleration sledge is used to verify the effectiveness of palletized load stabilization by means of an acceleration imposed to the load along the advancement direction. It is composed by a fixed base and a translating plane, on which the pallet is placed, and its motion law is configurable in acceleration (figure 4).

The supporting base of the sledge is a welded metal structure with rectangular base and it is configured in order to create a rigid body able to bear inertial stresses induced by the motion of the translating plane. The absolute value of these dynamic stresses increases with the increase of the acceleration imposed to the moving part and of the weight of unit load submitted to the test.

Also the moving part is a welded metal structure on which are mounted two asynchronous motors with planetary gearboxes. The value and the variability of the loads moved impose the use of a motion transmission system as rigid as possible, so it can be guaranteed the tracking of the trajectories imposed to the motors and it allows the repeatability of the tests.

This rigidity is entrusted to rack and pinion pair; the pinion is collocated on the output motor shaft, while the rack is bolted to the base, where are also bolted two linear ball guide on which slides the moving part.

The moving part that acts as a support for the load is delimited in front and behind, along advancement direction, from two panels, tilting at will.

The acceleration curve that controls the movement of the sledge is a modified trapezoidal type and it is characterized by the following phases:

- Acceleration ramp, configurable in duration. In this phase the acceleration is brought from 0 to the maximum selected value.
- Constant acceleration part, configurable in duration and absolute value.
- Deceleration ramp, configurable in duration. The acceleration passes from maximum value to minimum value (deceleration) passing through 0.
- Constant deceleration part, configurable in absolute value.

The control software verifies that the combination of parameters chosen by the operator does not lead to overcome the limits of stroke and maximum velocity of the system, and eventually forces him to modify the parameters.
Figure 4. Acceleration sledge.

Thanks to this application it is possible to evaluate load deformation when it is submitted to a certain pre-set horizontal acceleration, in particular it can be seen the tilt value of the load wall according to standard EUMOS 40509.

This standard is relevant in order to quantify the effectiveness of the wrapping during transport to prevent deformation or relative movement of the products, with a resulting elastic or permanent deformation of the load. The cause of these deformations is the horizontal inertial force that characterizes the transport, mostly road and railway transport.

Load rigidity is expressed as the maximum acceleration that the platform can reach without causing deformations or not acceptable movements of the load. This value is expressed in \( k \cdot g \), where \( g \) is the acceleration gravity.

Whatever the value of acceleration imposed to the sledge, the standard imposed a constant acceleration part of at least 0.3 seconds, to reach from rest condition in maximum 0.05 seconds. The standard imposes also some restrictions on the lateral panels, in particular the panel behind the load must be collocated at least 60 mm from the body and must have an inclination of at least 14 degrees with respect to vertical direction, creating a sufficient space for a certain deformation without contact between the two bodies.

In order to guarantee the rigidity level \( k \) the load must report deformations lower to the limits at the end of the test with acceleration \( k \cdot g \), where these limits are defined in the following cases:

- Permanent deformation of every product, along horizontal direction, must not exceed 5% of total height of the load. Anyway, if the load is lower than 1200 mm, the limit is fixed at 60 mm. Furthermore the deformation related to the 200 lower mm must be less than 40 mm;
- Elastic deformation of the load must not exceed, along horizontal plane, 10% of the total height of the load. In case of tilt of the load it must be considered the tilt angle of the lower face in order to determine the real load deformation;
- If the composition of the load includes different layers of product, the maximum vertical space that forms between two successive layers must not exceed 2% of the total height of the load;
- The products must not be damaged at the end of the test.

In figure 5, it can be seen also in this case the results of a test on the acceleration sledge, with the same load of the previous machine, wrapped with the same program.
Figure 5. Results on wrapping load during and after test on acceleration sledge.

5. Hexapod platform
The machine that is also called motion platform is able to move a body through its six degrees of freedom by means of six actuators that move the legs of the system. The system configuration is reported in figure 6. The system is defined kinematic parallel robot because it is constituted by elementary kinematic chains that sustain in parallel the same end effector. It differs from a serial kinematic robot that is characterized by the absence of closed path within its kinematic chain.

Figure 6. Mechanical assembly.

The hexapod parallel kinematic machines with extensible legs are also indicated with the name Gough-Stewart platform; the first realized a hexapod for the handling of tires to execute dynamic tests while the second published a relevant article about the use of Gough hexapod as simulator [40].

The advantages that the parallel kinematic configuration presents, with respect to the serial one, are:
- High dynamic performance (in particular if it can be used slender legs);
- Configuration modularity (economic saving);
- High rigidity and precision.

Otherwise the negative aspects of the parallel configuration are:
- Difficulty in realizing universal or spherical joints sufficiently rigid and precise;
- Bulky configuration with respect to the volume of work;
- Volume of work of strange shape;
- Isotropic behavior within volume of work;
- Risk of collision between legs;
- Limited possibility to incline the end effector.

The considered model is called MB-E-6DOF-2x-xx00KG, where MB means Motion Base, E indicates the use of electric actuators, 6DOF expresses the number of actionable degrees of freedom, 2x indicates the stroke of the actuators and depends on the performance type chosen for this model, as well as the payload, indicated as xx00KG.

The floor frame is attached to the ground by means of three separated floor plates, connected to the adjacent through a joint block that supports two joints on which are mounted two electric actuators. These joint blocks are bolted on the ground and are interconnected by floor beams (figure 7).

![Figure 7. Floor frame assembly.](image)

The moving frame is generally customer-supplied and interfaces with three top joint blocks, each supporting two electric actuators. So overall there are six actuators between floor and moving frames.

The beams that are represented in figure 8 support the top joint blocks but they are meant only for transportation and correct interface with the moving frame. After the installation they were removed because they reduce the payload.

![Figure 8. Mounting the top joint block to the frame.](image)
Each electric actuator is attached to the floor frame and to the moving frame by a dedicated joint (figure 9). The motion base electric actuator lower joints are bolted onto the bottom joint blocks. The electric actuator upper joints are bolted onto the top joint blocks. The lower and upper joints are universal joints that allow rotation in two degrees of freedom.

The servo motor peak torque ensures that sufficient acceleration or deceleration is possible in every position. The mechanical brake locks the electrical actuator in some failure modes or when the simulator is not in use. Finally the possibility to include magnetorheological fluid devices for an active control and further functionalities was investigated (as proposed by [41]).

![Electric actuator diagram]

Figure 9. Electric actuator.

5.1. Design of pallet fastening

The moving frame, used as pallet fastening, was designed to be compatible with machine supports and can be seen in figure 10.

![Design and FEM validation of the moving frame]

Figure 10. Design and FEM validation of the moving frame.

To simulate the pallet motion it is designed a fastening system that comprehends a wood loader that has to be fixed to the moving frame, on which the palletized load is placed.

The wood loader is fixed to the frame through three perforated sheets that are connected to the tubular elements placed in the lower part of the frame with some threaded rods. These rods are closed from both sides with a nut preceded by a washer and a spring-washer (figure 11).

Once the loader is fixed we had to constrain the palletized load. It was limited along its sides from four angular components connected to the loader with four plates placed below it. Also in this case the connection is performed by means of threatened rods closed by nuts. Finally to constrain the vertical movement of the pallet to the platform movement the loader presents holes in different points (where it can be seen the washers) to allow the insertion of wood screws that fix the pallet to the loader.
As it is important to assure that the pallet is correctly fixed to the platform is equally fundamental to know that the designed moving frame does not have a natural frequency in the frequency range excited by the system. In this case the platform start to vibrate and does not transmit the correct stresses between hexapod and pallet (the ones acquired in the tests).

To compute the first natural frequency of the steel component that was designed and that is used as moving frame of the system we used the finite element method (FEM) by means of integrated function in Inventor. Inventor is not a specific software for the finite element analysis but allows us, through a preliminary analysis, to estimate the natural frequencies of the body. After the setting of an automatic mesh and the definition of physical properties of the material we run a modal analysis that compute the natural frequencies of the body and the modal shapes. The results show that the first natural frequency of the system is around 90 Hertz. Considering that the data coming from our tests are used in the system after a filtering at 50 Hertz we can conclude that the platform does not influence the vibrations transmitted to the hexapod, allowing to correctly replicate them on the pallet and so on the load placed on it.

5.2. First use of the hexapod platform
The configuration shown in figure 12 was physically implemented and represented, to the knowledge of the authors, the first ‘transport simulator for packages’. During the validation session, performed in MOOG Inc, Holland, after an initial performing test, it was programmed with transport test data acquired by means of our measurement system. The system proved to be able to return results (in terms of movements and accelerations) compatible with reality and readable from a dataset.

6. Conclusions
The success of the first simulations and the potentiality to replicate every type of transport or critical event thanks to the developed measurement system combined with Moog hexapod has led the laboratory to represent a first-class test environmental for this special products. Therefore this machine
is added to the current one, able to study by standard tests the effect of transport on the stability due to wrapping of the palletized load. Meanwhile an instrumented pallet will be used to extend the available data related to transports, for every kind of product, transport, road and other parameters and configurations required by the customer.

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