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Measuring the Mechanical and Climatic Conditions Encountered by Palletized Products in Handling and Transport

Handling and transport can turn out to be a disastrous experience for the integrity of goods and products. This fact has encouraged the attention of producers towards the development of measures aiming at maximizing this integrity. At the same time, to obtain really effective solutions, the environmental conditions and the level of stress acting on these products during their way from the producer to the final customer have to be detected. This paper illustrates some between the most relevant methods and experiences for monitoring palletized products.

Keywords: *packaging, transport system, vibration, pallets, stretch wrapping.*

1. INTRODUCTION

Nowadays, every solution for packaging has to ensure a package minimized in terms of volume, commensurated to the specific type of packaging (primary, secondary, tertiary) [1, 2], but also a proper level of protection against mechanical and environmental stresses [3-5].

In respect to a commercial strategy of Total Quality [6], aiming at reducing all transportation costs, packaging can tend to carry a larger quantity of products on the market, neglecting the effective protection and, for this reason, accepting risks on product's integrity. But, inappropriate packaging can easily turn into products' damage and, lastly, costs. With the scope to provide a case of the potential losses in business related to damages in packages, it is noteworthy to report that Walmart, probably the biggest food supply chain in the world, declares that the effects of damaged products can reach 2.4 Mld of dollars in a single year [7].

After definitely detected the relevance on business of a good package, each industry has to choose between two opposite strategies: decide to patiently accept these undesired losses or try to increase the level of protection during transport and handling accepting additional costs for a better package.

This second option is possible increasing, for instance, the cushioning materials or the stretch wrap film used for packaging. But this case also means that neither the pack nor the packaging process are optimized. Adding, hidden costs can emerge as a result of this over - packaging, as those associated with larger disposal, increased traffic, pollution, accelerated road deterioration… [8].

The customers' desire of perfect products on the market, merged with the producers' necessity to work for the highest efficiency and for highly optimized costs, opened a new scenario where knowledge is a base for further consideration on packaging techniques.

This paper provides a help reporting a wide-ranging state-of-art on mechanical and climatic conditions encountered by palletized products during handling and transport phases, together with several details on the technical solutions used for their experimental measurement. Furthermore, it collects and synthesizes a large number of investigations dealing with "safety in packaging", considered in terms of norms, procedures and laboratory tests. In particular, it is noteworthy that several international institutions provide guidelines and procedures to be conveniently used for testing artefacts.

One of the most prominent institution is the International Safe Transition Association (ISTA) that provided different protocols for testing products as ISTA 3E [9], ISTA 3B [10].

2. FACTORS DETECTION

In order to detect the external factors palletized products are submitted to, it is necessary to install specific equipment and experimental devices, as accelerometers, temperature and humidity sensors.

2.1 Instruments for detection

Accelerometers are the common devices used for investigating vibrations.

The detection system has to be pre-configured in consideration of the specific phenomena under inves–tigation. In the case of transports on truck, for instance, a 0.1G trig-level can be used for measures, also permitting to delete the noise. Instead, a 0.5*G* trig-level has to be preferred in order to distinguish shock events, especially in combination with a 0-100Hz bandwidth [11]. In [12], it is demonstrated that vibrations transferred to a pack, when located on a truck load bed, present a bandwidth between 40Hz and 55Hz, while the frequency due to suspension are, typical, 3-4Hz and 15-20Hz due to tire.

The vehicle vibration level is commonly evaluated by using power spectral density (PSD) or root mean square (G_{rms}) values [12].

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Whereas instruments used for detecting the oscillations, during experiments different authors equipped the vehicle with GPS in order to precisely verify the track and a camera for identify the reason of each shock or particular disturb. Indeed, inputs from these different devices have to be perfectly synchronized.

According to [13], the detection of environmental factors, as temperature and moisture, has to be considered. These factors effect in negative on products and packaging (as carton, films etc.). For instance, in a wrap film, the raising of temperature implicates a relaxation of the stretch film with reduction in the force of containment. On the other hand, when moisture raises, it is possible to observe a softening effect on the paper/carton layers and, sometimes, the presence of condensation inside the pack. The continue monitoring of temperature and moisture parameters during the transport, is a relevant aspect in the case of medical products, as detailed in [14], where the correlation between vibrations and temperature is analysed.

2.2 Detecting vibrations on truck

Undoubtedly transport with trucks represents the most common solution for moving goods and materials. It is quick and functional, permitting a direct link between producer and customer. Moreover, with the exception of very particular situations, it is cheaper in comparison with trains, vessels or air cargos [15].

A large number of studies investigates the transport on track, reporting experiments with the scope to characterize and understand the vibrations transmitted to the products during the transport phase. They use to primarily consider aspects related to the track conditions (as the used of paved [16, 17] or unpaved roads [18]). Firstly, measures reveal that the amplitude of vibration does not represent the only aspects to be considered for evaluating the damage effect on packages, but also the frequency is noteworthy. Furthermore, experiments show that physical events causing vibrations are naturally random [19], with major density in the case of urban paved or unpaved road, instead of highway.

In [11, 12, 19], where vibrations on a truck were monitored in the cases of different roads and speeds, it was also demonstrated the benefit offered by air-ride suspensions (respect to other solutions as spring leaf suspension) in damping the vibrations, especially on the longitudinal components (<0.1G), and, sometimes, on the lateral components.

As general result, it is possible to confirm that the higher is the speed of the truck, the higher is the Grms observed in each direction: vertical, longitudinal or lateral. But the same result also indicates that the effect of vehicle speed on the Grms in the case of vertical vibrations is stronger at a lower speed, but slighter at higher speed.

Moreover, for a correct analysis of signal, it is recommended to separate shock events from the overall signal. The PSD (Power Spectrum Density) in the case of shock events is demonstrated to be more evident than the overall signal (figure 1).

When the effect of a shock event is removed from the overall signal, it is observed a deep change in the PSD level, especially notable in the vertical direction and for frequencies lower than 20 Hz. This change increases with the truck speed.

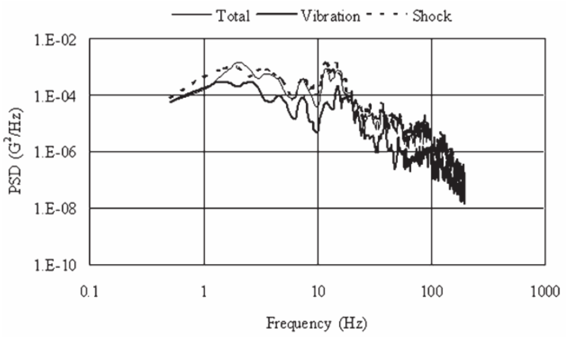


Figure 1. PSD vertical acceleration [12]

In [20], an additional analysis of truck transport environment is reported. It generally reconfirms that vertical accelerations are higher than longitudinal and lateral ones. But, it also highlights how the specific structure of the vehicle, if not properly considered, can induce mistakes in detection and in final considerations. In fact, it was initially noted a high component of vibration at 100 Hz, then explained as due to the rear truck bumpers impacting on roads asperities.

The relevance of bumpers also introduces the fact that, even the presence of a load on the truck has the effect to reduce its accelerations, as anticipated in [11]. Then, a new parameter, the magnitude of load, has to be taken in count for further considerations.

For having an idea of the effect of loads on vibrations, a recent experiment compared measures provided by two trucks, similar in all technical characteristics, but differently loaded [21]: with 60% and 150% of their maximum truckload. Data are displayed in figure 2 and showed a significant reduction in peaks of acceleration (G) in the case of the overloaded truck.

Adding, the RMS acceleration values for the overloaded truck increased as a function of truck speed. This result suggests that truck speed has a relevant effect on the vibration levels even when the truck is overloaded, but also that road roughness has a considerable impact on transport at higher speeds.

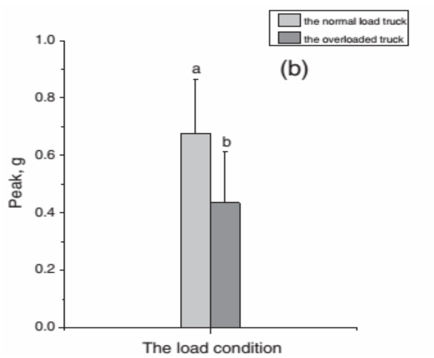


Figure 2. Acceleration peak [21]

In [22] the case of transports by tracks of loads significantly lower than the truckload (LTL - Less Than Truckload) was investigated, examining the vibration transmitted on loads from the bed trailer (figure 3). In particular, it was demonstrated that the PSD of vibrations was higher respect to the ISTA standard suggesting to pay a special attention to the payload.

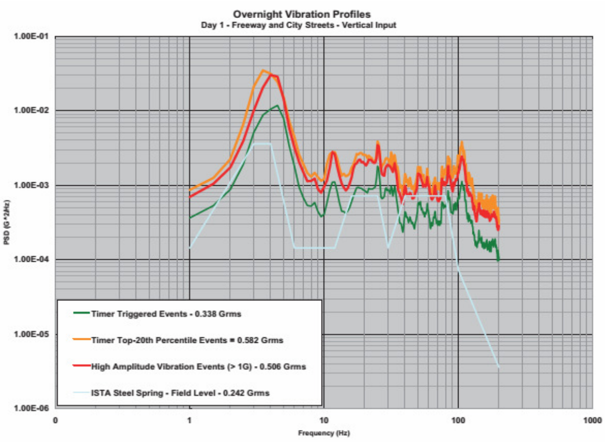


Figure 3. PSD vertical for urban road and highway [22]

Referring to the aspect of products' damage during transport, several investigations were focused on the food products.

In [23] an ANOVA was realized considering the transport modality defined by truck type (n° axle, suspension type, etc.), type of roads and velocity range. All these three parameters are demonstrated to have a relevant effect on the product damage. It was also noted that, as expected, vibration quickly increases with speed, but also that bandwidth reduces by major loads (figure 4 and 5).

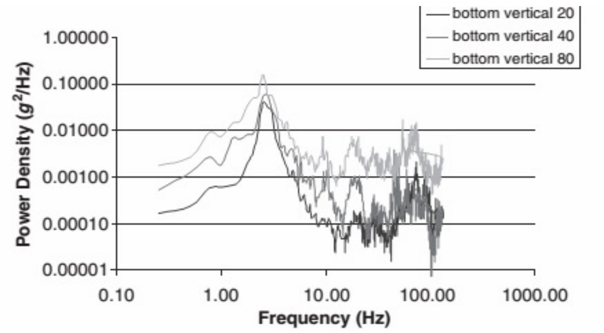


Figure 4. PSD vertical of 2-tons truck [22]

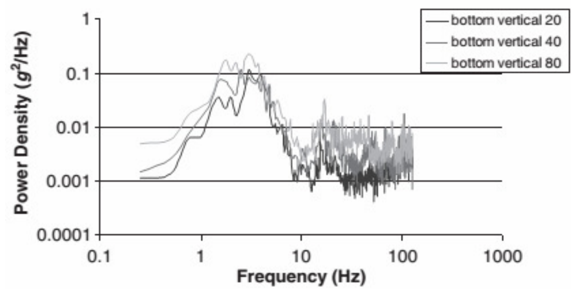


Figure 5. PSD vertical of 6-tons truck [23]

In [24] dynamical stresses on food package in travelling from Spain to Italy were monitored. Accelerometers were mounted on trailer, closer to the air-suspensions and on the track's rear (figure 6). Results, in terms of PSD along the trailer, are displayed in figure 7.

Acceleration changes along the load, raising from the bottom to the top of the column of piled products, as reported in figure 8. The r.m.s. acceleration is largely amplified from bottom to the middle and top positions, especially in the range 13–25 Hz. At the bottom position, the phenomenon of vibration is less evident and mainly related to the range of 19–33 Hz. The highest amplification occurs at 21–22 Hz in the cases of top and middle positions and at 27 Hz for the bottom position. These amplitudes and frequencies are clearly dependent of load material type and packaging.

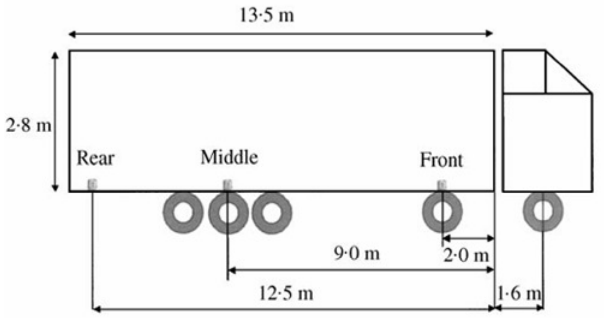


Figure 6. Accelerometers locate [24]

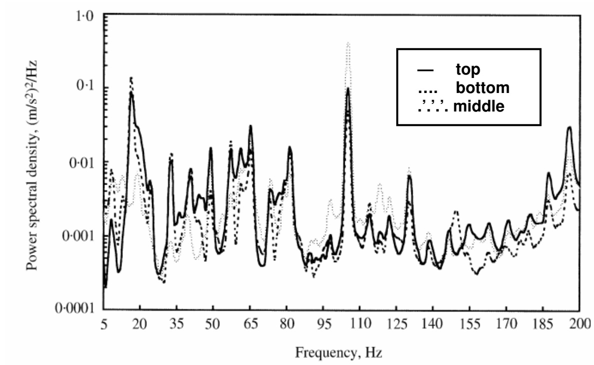


Figure 7. PSD of trailer [24]

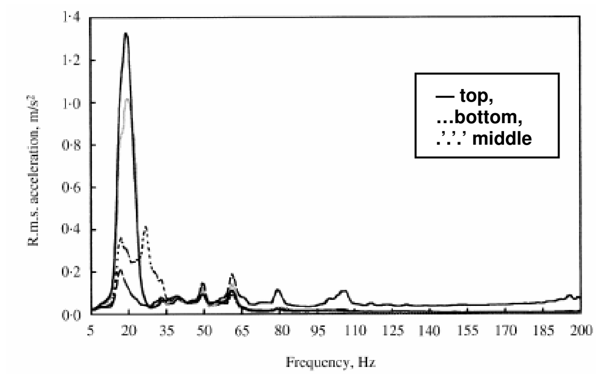


Figure 8. Acceleration peaks [24]

A precise decomposition of the overall signal in basic components is useful with the aim at repeating damage tests in laboratory.

In [25] accelerometers where installed as in figure 6, but on two different trucks, for monitoring the damage on shell eggs during shipment.

This investigation was not limited to record signals, but also to reproduce vibrations on a shaking table.

For a deeper analysis, several micro-accelerometers were directly installed on eggs and at different heights along the column of piled products. The highest value of r.m.s. accelerations on eggs where measured in the range of frequency 5-20 Hz and, particularly, in the eighth (uppermost) box of the column over the rear part of truck, stressed by a PSD profile from 5 to 80 Hz.

This research confirms that higher values for PSD are reported at low frequency and that the vibrations are higher on the rear part of trailer (respect to middle and front). It is also noticed that the vertical positioning on trailer significantly effects the risk of product damage. This result is also confirmed by [26] where vibrations along the height of a container were monitored, highlighting a decreasing from top to bottom (figure 9).

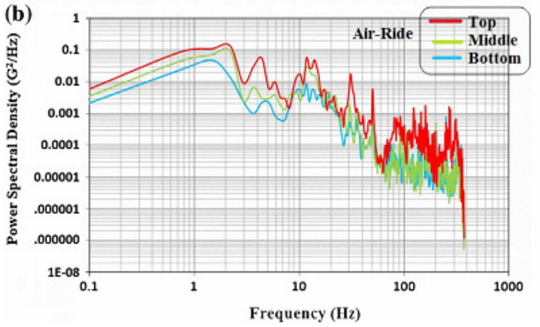


Figure 9. PSD along load height [26]

This correlation between height and vibration was investigated by an ANOVA confirming that in higher product, there is a significant possibility of damage of the last layer. In the 0.1–5Hz bandwidth (representing the first vibrational mode in the experiment), it was measured 0566 G2/Hz, 0.0861 G2/Hz and 0.0869 G2/Hz, for, respectively, bottom, medium and top locations.

The dynamic response of piled (stacked) products were investigated inside various studies using experiments for validating mathematical models and, then, simulation for investigating different conditions. A correct friction model for simulating the contact between products and with the packaging materials seems to represent a fundamental aspect for obtaining good results [27]. This approach of modelling the entire system by an assembly of interacting elements, each one characterized by a bumping effect, is not so far from what commonly done for automatic machines where the dynamic optimisation also passes by a special design and an accurate material choices. [28-30].

In [31], the response of a pack was analysed by a laboratory model with the aim at reproducing the dynamic behaviour, together with the effect of several boundary conditions. A sine motion was used for forcing the system, a condition that is less representative of reality respect to random or data collection from experiments. A parabolic shape in PSD with frequency increased was observed; besides the oscillation decreased from top to bottom of model (figure 10).

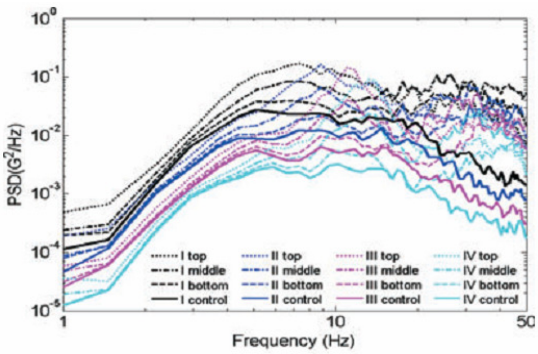
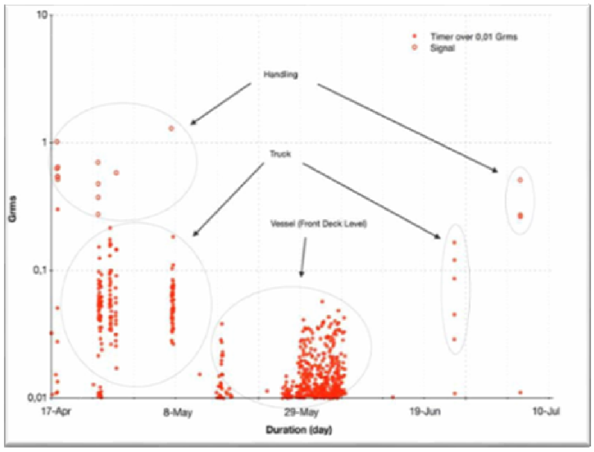


Figure 10. PSD based on frequency [31]

Considering the general scope to realize packages able to resist to the larger gamma of situations, researchers have spent a lot of energy trying to characterize the environment conditions especially in uncommon circumstances. For instance, in the already presented [13], an intercontinental travel from Hungary to South Africa was carefully monitored. Temperature and moisture were recorded with special attention since the route crossed the equator. A relevant change in both parameters was highlighted (T°: 9 – 27 C°, RH: 30% - 80%).

At the same time, accelerations were monitored and their values, expressed in terms of Grms (figure 11), permitted to distinguish the different phases of transport (as handling, travel on truck, travel on vessel, etc.).



Event	Activity	Acceleration (G)	Orientation
1	Handling at port	13.11	Flat – Bottom
2	Handling at storage	10.16	Flat – Top
3	Handling at storage	7.54	Edge – Bottom Right
4	Handling at storage	7.54	Flat – Left
5	Handling at commissioning	6.72	Flat – Left
6	Handling at commissioning	5.25	Edge – Front Left
7	Handling at storage	5.08	Edge – Left Back
8	Handling at port	4.95	Flat – Bottom
9	Handling at storage	4.50	Flat – Back
10	Handling at commissioning	4.48	Flat - Back

Figure 11. Analysis of G_{rms} value during transport [13]

Results show that the most severe physical events happened when the pack was handled at the ports or during transfer between storage and loading on trucks. Vibrations and shock levels were generally very low when the package was transported by ship.

Adding, it is possible to note that vibration along the vertical axis produced the highest Grms pick (0.209 G) and that it occurred during the transport on truck. On the contrary, highest peaks during transport by vessel or ship were significantly lower (0.127 G).

The fact that the quality of goods can be really damaged during transport by these values of acceleration was checked and confirmed in [32] where fruit located in the rear part of a trailer was almost damaged (while fruit at the front was almost saved). Several levels of anchoring were investigated, confirming that fruit suffered a lower damage when strictly fixed to the truck. Thus, a perfect fixing also represents a practical suggestion in order to reduce vibrations on products (and related damages).

In the same research, it was also possible to verify, as a generic result, that an incorrect position of sensors on loads or on trailer can easily compromised the test providing misleading results. This aspect is even investigated in [33], where the detection was done on the trailer in a number of points larger than usual thanks to micro-sensors. (figure 12).

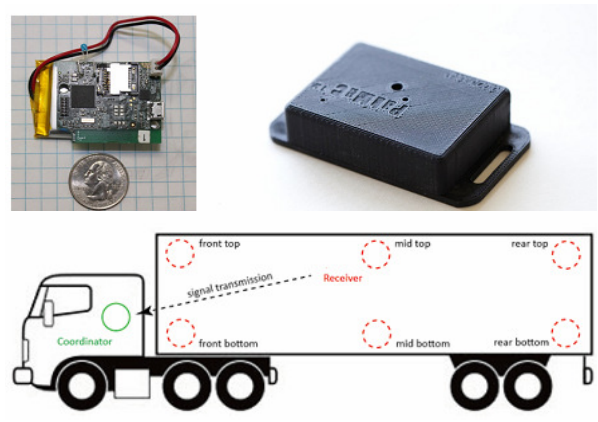


Figure 12. MEMS sensors and their location [33]

a. Detection vibrations on other vector.

Bearing in mind how long and complex a modern distribution chain can be, several transport systems different from a truck have to be preferably taken in count.

It is the case of a category of special vehicles which handle materials and products in the warehouse, as forklift. Thus, how forklifts can damage seriously the product has to be carefully considered.

A new standard for test on the forklift horizontal impacts was recently published ASTM D4003 [34], and reforming the previous version. Specific formula, as detailed in [35], permitted to re-calculate the acceleration during impacts, demonstrating a previous overestimation. In brief, the old ASTM referred to testing conditions and higher *G* range, respect to reality.

A comparison between several reference standards for modelling the forklift impact was presented in [36]. This article investigated, in particular, the impacts against containers used in agriculture with the aim at understanding how impact waves are transmitted across the containment materials. The study also searched for the design of a better packaging in order to protect specific agricultural products. The lesson learnt deals with the fact that wave transmissions is less sharp in the case that a larger quantity of carton boxes is present. Substantially, more bodies offer more absorption. Furthermore, it is also demonstrated that, if the shock happens on the edge, the transmission of impact waves prevalently occurs along the height.

In [37] the effect of load containment of wrapped materials when handled by a lift truck, equipped with clamps instead of forks (for carton clamp handling) was studied. Doing an ISTA 3B test [10], it was noticed that the force of containment provided by stretched films decreases during transport due to the continuing shocks.

In particular, the unit load for both patterns slipped considerably more at the back (closest to the driver) than at the middle or front of the load. The middle sector exhibit more slippage than the front of the load. Handling the unit load, i.e. clamping the load, moving the load to an obstacle course, traversing the course and unclamping the load, had a significant effect on the containment film force for both stacking patterns.

2.3 Detecting vibrations on trains

Other studies were focused on vibration transmitted during a rail transport.

For instance, [38] demonstrated that, in a wagon travelling throughout India, vibrations at lower frequency are 10 – 70 times more relevant in magnitude than vibrations at higher frequency. Then, oscillations at low frequency can be considered as having a major responsibility on damage in the case of rail transport.

At the same time, measures confirmed that, on the trucks or trains, the vertical components of vibration can be always considered the most relevant, larger than the lateral and longitudinal ones.

Since several features in the Indian railways can be significantly different in respect to the Western railways, in [39] a measures of vibration on freight trains was also realized for different routes throughout Central Europe. It was focused on detecting the acceleration respects to the three axes. Comparing these measures with results of the others investigations, it is possible to highlight as the train transport conditions in Europe are generally better than what occurs in North America or India. In particular, it was noted a peak of acceleration around 10 Hz, lower than North America and India.

In [40] a packaging optimization was realized in the case of train transport by inserting cushioning materials in order to improve the products protection. The optimal solution was also compared, in terms of vibrations, with prescriptions coming from standards (figure 13).

It is noteworthy how these standards are barely able to respect real cases. This discrepancy was investigated not only in terms of overall vibrations, but also using a separation in frequency, directions or shock events.

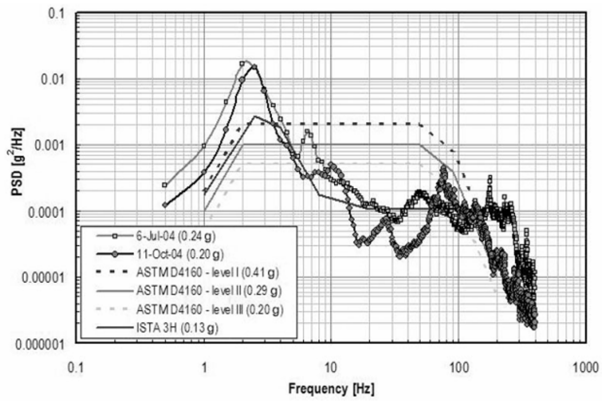


Figure 13. PSD of vertical vibration [40]

2.4 Detecting vibrations on air cargo

Vectors other than truck and train were also analysed as for air cargo. In [41] the levels of protection offered by two shipping companies was investigated with the additional aim at establishing the efficiency of several technical solutions in insulating the cargo from vibrations. In this case, the trig-level for accelerometer sensors had to be properly changed to 14 *G*.

Another experiment on air-cargo was realized [42], detecting the vibrations on an airport pallet dollies, used for handling air-cargos (figure 14). In particular, frequencies in a range between 50Hz and 80Hz were detected, unpresented on other vehicles. It means that severe and unexpected damages can be induced on products even in the case of short legs. Adding, it also confirmed that, in order to permit a correct evaluation of the logistic chain, every different vehicle has to be considered. In respect of this, in [43], the detection of vibrations was also realized in the case of carts for storage, manually moved.

Figure 14. Instrumentation of dollies with data loggers [42].

3. SIGNAL ANALYSIS AND SIMULATION

Analysing measures provided by these experiments, it is quite clear how current test standards are far away from recreating the environment conditions that occurred in real cases of transport.

Surfing the database of shocks related, for instance, to a transport by truck, it is possible to observe, in fact, that shock events are random, dependent from the various obstacle that truck encountered.

This situation can also represent a relevant problem respect to the correct comprehension of results and several methods had to be developed for data analysis.

3.1 Consideration in signals analysis

The [44] deals with the development of a technique for decomposing the overall signals of vibrations, non-stationary randomly distributed, into their constituent Gaussian elements. The hypothesis that random non-stationary vehicle vibrations are essentially composed of a sequence of zero-mean random Gaussian processes of varying standard deviations is tested and the paper reveals that the variations in the magnitude of the vibrations are the cause of the leptokurtic, non-Gaussian nature of the process.

In [45], the problem of the correctness in the sampling of signals was proposed, aiming to validate the effects of a specific sampling on frequency, bandwidth, trig-level, on PSD and on RMS of vibration. It is noteworthy, in fact, that the vibration surveys are most sensitive to the sampling period, especially when the vibrations are highly non-stationary.

In [46] the applicability of run-test as mode for identifying the non-stationarity of vehicle vibrations was investigated, while [47] uses a Monte Carlo method for its versatility in simulating random events.

In [48], a simulation was developed, able to model several pavement profiles, with the aim at optimizing the whole packaging process. Inside this simulation, based on stationary conditions, it was also confirmed that the vertical oscillations are largely prevalent as direction of stresses. At the same time, it also demonstrated that, limiting the model to the vertical directions, can be surely provide fast and cheap results, but often far away from real cases.

In [49] a new procedure for reducing time and the entity of data was proposed. It is reported that the simulation lasted 2h and 45 min on the base signal of 15h when accelerometers were located on the rear trailer and recorded the vibrations.

With the same aim to reduce time and data in experiments, in [50] the concept of MTTF (Mean Time To Failure) was used, comparing the measure of accele–ration G with the test of duration used for evaluation of product damages. This method, if correctly applied, can be used for correlating life – stress with damage.

A critical note dealing with the procedure for interpreting signals was cited in [51], where was judged the semi-stationary simulation (RMS=cost) as not properly reliable, as [44] and [48]. Moreover a PSD manipulation involved a re-arrangement of a real environment conditioned, and an ISTA PSD are not properly reliable. The same [51] also proposes a method to release the absence of data recorder, but which it requires to know the vehicle response.

3.2 Laboratory test

With the aim at performing an in-depth analysis of product damage and its occurring mechanisms, researches also realized inside the laboratories. This approach permits to simplify investigations avoiding experiments of field, but, on the contrary, to be valid, it needs a precise knowledge of environmental conditions. Moreover, for executing reliable experiments inside the laboratory, it is often necessary to re-adapt the available testing machines extending their functionality. For example, referring to the transport by truck, it was highlighted that the major part of vibrations is related to the vertical component. But it is also demonstrated that important longitudinal or lateral components are present in several practical cases. Then, a testing machine has to be able to analyse the dynamic behaviour of a load when all these directions are combined. In this sense, in [52] it is recommended the use of a 6 degree of freedom (DoF) shaking table, in addition to the simultaneous detection on a large number of points on trailer. The research showed, once more, that the real movements of the truck load bed during transport cannot be properly described with vertical acceleration alone. In order to produce a clearer interpretation of the results, the discussion is focused on the lower frequency range (below 20 Hz), although it is declared that similar considerations can be made in other frequency ranges.

The lowest considered frequency was 2-3Hz where the vertical component is dominant. Furthermore the pitch contribution causes the RMS acceleration value recorded to be dependent on the sensor position in the trailer platform. The second interesting frequency with regard to the load platform movements was located in the shipments analysed at around 7–8 Hz. In this case, it was demonstrated that vibrations at these frequencies are subject to important contributions from all axes, translational and rotational, and only the yaw can be neglected without significant effects. Finally, both trucks under investigation displayed dominant lateral movements, between 10 and 15 Hz.

It is evident that this behaviour cannot be addressed by only measuring the vertical direction. In [53] a 6 DoF shaking table was used for investigating the modal vibrations of stacked product (figure 15).

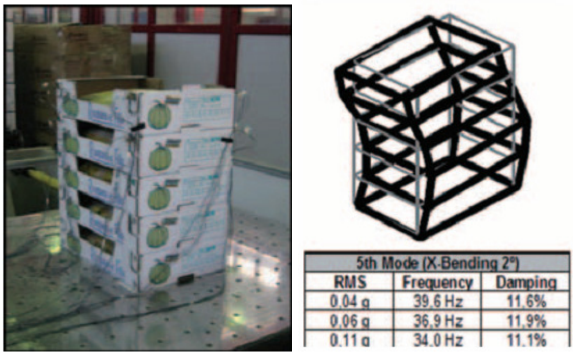


Figure 15. Available accelerometers (sx) and 6° mode of vibration (dx) [53]

Concerning the non-linear behaviour of deforming containers, this is an effect normally neglected in laboratory testing procedures. According to the results of the already reported investigations, in vertical direction, a variation in RMS amplitude of the random profile produces a significant shift in the resonant frequency with an associated dynamic stiffness reduction that can reach 50%, and the change in damping influences the amplification factor in packaging resonances.

In [54] a method is proposed for test acceleration based on the Miner–Palmgrem rule for fatigue. It can be affected by the non-linearity insofar as the increase in the power spectral density in the response of the system is not equivalent to the increase in the Power Spectral Density (PSD) applied to the vibration table.

But laboratory tests, apart from measuring vibrations, can be also used for a direct investigation of damages. In this way, a FRF (Function Response Frequency) model was developed, in order to better understand the dynamic response of product [54]. This model was also improved considering two (instead of one) sub-structures, representing truck and load [55].

An additional refining of this model was used in [56, 57] with the aim of examining the dynamic behaviour of real systems in respect to real conditions of transport (as shown in figure 16 in the case of a fridge on a pick-up).

In [56, 57] it was also reconfirmed that results from the mathematic a model were quite close to the experimental measures.

Also [58] refers to the opportunity to use the FRF prediction for optimizing packaging, avoiding load damage. In particular, a method was optimized to predict the response for two sub-structures (vehicle and load), using a dummy mass method for introducing the system stiffness in the model.

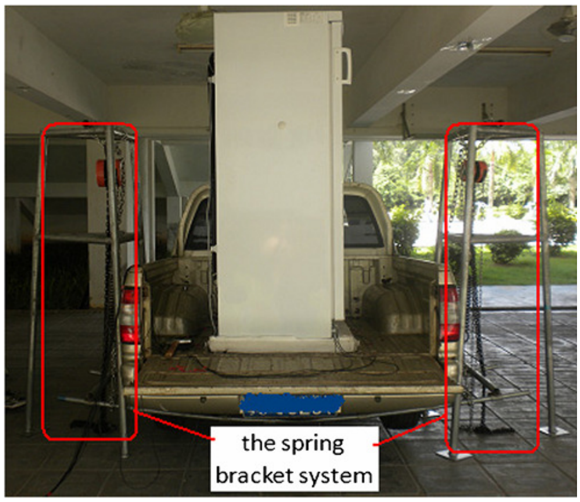


Figure 16. Analysis system [57]

Several experiments on packaging also include consideration on protection materials. In [8] the grade of protection and stiffness offered by these materials against vibrational stresses was evaluated by experiment. On the same argument, [59] proposed a mathematic model to simulate the drop load, through introducing a new model of friction inside a box. This model seems closer to real cases. Anyway, other formulations for a different modelling of the frictional effects have been developed, as in [60].

Despite a drop test is sometimes proposed to simulate a forklift effect in presence of cushioning materials, as inside ASTM standard [61], this test is not persuasive in covering a stress life damage of products, as demonstrate in [62].

On the market there are several kinds of cushioning materials and also this variability was investigated. In [63] a hybrid solution for modelling the vibration of containment was proposed. The model was based on a multibody analysis, where the stress/strain curve of protection material (Eperan™ XL 38 in that case) was already known. Anyway, it represents an innovative approach toward the modelling of the general problem, but further refinements are required.

In [64, 65], multi-layer cartons were considered with the aim at predicting the response of packages to the compression. It was immediately noted a good correspondence with reality, including the possibility to predict and reproduce buckling phenomena.

Between the other cushioning materials, the cardboard is an important material, typically used for primary and secondary packaging, but also as intermediate layers in specific palletized products (as a water bottles). The structures of cardboard could be single-wave, double-way, gripper cardboard or honeycomb types. These complex structures improve the functionality of this material, but add complexity in modelling their behaviour. In particular, the honeycomb is used whenever a very good energy absorption during impact is request [3]. In this case, it is observed [62-65] that, not only the cardboards, but also the air inside the cells, have a cushion behaviour (figure 17).

Apart from the cushioning materials, the effect of wrap film on stability and protection has been recently investigated also. In particular, it was noted that wrapping solutions can be used to toward an optimal package. By a proper wrapping methods, it is possible, in fact, to increase resistance and stability of palletized products.

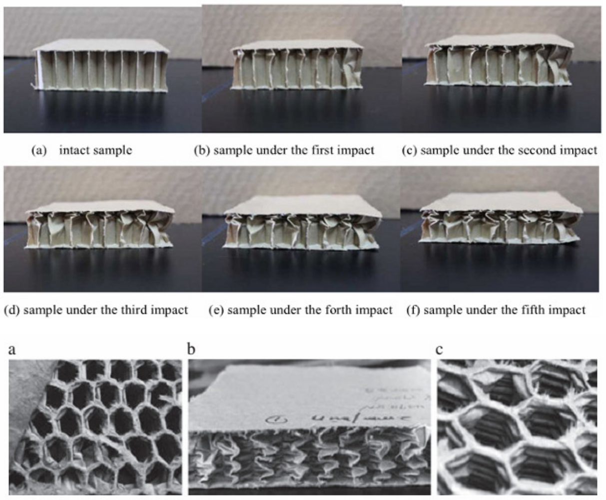


Figure 17. Honeycomb panel after impacts and crushing [3]

In [66], the correlation between pre-stretch and stretch film, force containment, and load containment was analysed. As unexpected result, it was noted that, after an initial positive influence, the level of pre-stretch in the film does not provide a significant impact on stability and protection of packaging. This effect is probably related to the fact that the elastic material, used for the stretch film, rapidly enters in the plastic region.

3.3 Testing procedure

Considering the relevance in terms of quality assurance, productivity and cost-efficiency, a large number of manufacturing industries are interesting in performing in-depth examinations on potential mechanisms of damage during transport, especially if focused on their specific products and when environmental conditions can be controlled in accordance with real cases. These test are realized not only for testing the resistance and the stability of packaging, but also to optimize it in terms of materials, weight, process time, costs, etc..

These researches can be surely realized inside the labo–ratories, with the aim of saving time and costs in respect to an in-field testing session, but proper equipment is needed.

Vibration or acceleration tests can be only realized by uncommon equipment in order to simulate a large gamma of conditions a package can face during the transport. At the same time, these tests have to be referred to standards.

A specific procedure for testing the efficiency of the packaging process is here proposed. It combines the use of a vibration table and an acceleration sledge. Tests refer to the ISO 2247 [67] for the vibration table and to the EUMOS 40509 [68] for the acceleration sledge.

In particular, after packaging, the wrap product is tested on the vibration table using 2Hz for 10 min. and increasing the frequency up to 3Hz with 0.5Hz step (figure 18).

After this first test, the same product is also tested on the acceleration sledge applying 0.5g for 0.3s and then equivalent deceleration. The elapse time between acceleration and deceleration is 0.05s (figure 19).

Every damage or displacement of the load is noted.

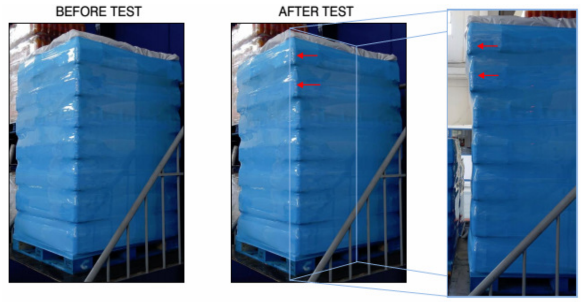


Figure 18. Vibration sledge testing 2.5Hz

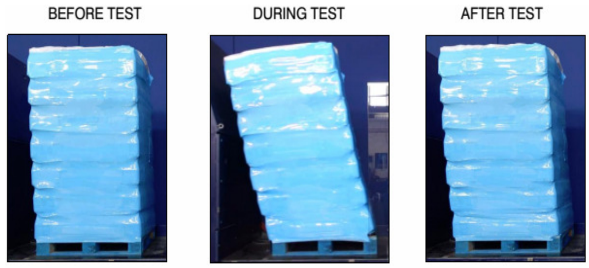


Figure 19. Acceleration sledge, testing 0.5g

4. CONCLUSION

This paper synthetizes the state-of-art of measurement stress on packaging products. In Table 1 and Table 2, a classification of references is reported.

Main results can be considered as:

- the damage strictly depends on vehicle and its structural conditions;
- the location of products on vehicle has not to be casual;
- it is necessary to use a proper quantity of cushioning material and a correct location;
- the reproduction of environment conditions, as measured by experiments, represent a better way toward more reliable packaging respect to the application of norms or theoretical models;
- it is advisable to reproduce vibrations on a six DoF shaking table (instead of 3 DoF);
- it is advisable to considerate an entire stress life of packaging material;
- it is noticeably better to take into account the solutions including the reproduction of all the real motions at the same time, instead of analysing single vibrational mode
- stretch films can provide a useful way toward the op–timisation of stability in the case of pelletized products.

ACKNOWLEDGEMENT

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Table 1. Summary of references in respect to the phenomena under investigation and the type of experiment

[1] [2] [3] *Experiment*		*Phenomena*				
		Vibration Measures	*Climatic Measures*	*Product Damage*	*Cushioning Material*	*Pallet Loading*
On field	*Truck*	*11,12,13,14,15,18,19,20,21,22,23,24,25,26,30,35,49,53,59*	*14,15*	*23,24,25,26, 29,30,59*		
	Forklift	*32,33,34,40*				
	Air cargo	*38,39*				
	Vessel	*13*	*13*			
	Rail	*35,36*				
In lab	*Signals processing*	*12,37,41,42, 43,44,46,47*				
	Stacked packaging	*28,27,50*				
	Safety	*55*			*3,55*	
	Simulation	*8,16,45,48,17,49,44*	*4*	*64,65,58, 31,9,10*	*4,63*	*1,2*
	Model Validation	*53,52,51,54,55,47*	*5,62*	*6,57,60*	*56,60,61,62,5*	

Table 2. Summary of references in respect of the types of outputs and experiment

Experiment		*Outputs*						
		Load Containment	*PSD Evaluation*	*Vibration Level*	*Mathematical Model*	*Test Procedures*	*Time Compression*	*Product Damage*
On Field	*Truck*		*13,15,20,23,35*	*11,12,19,21,22, 24,25,29,30*				*10,14,23,24,25,26,29*
	Forklift	*34*	*40*	*34,39*	*32*	*39*		*10,33,*
	Air cargo			*38*				*38*
	Vessel							
	Rail		*35,36*					
In Lab	*Signal processing*	*50*		*12,19*	*16,17,18,27, 41,42,43,48, 55*	*37,41,42,48*	*46,47*	*59*
	Packaging systems	*63*		*3,8*	*5,56,60,61,62*	*56*		*3,4,56,59*
	Stacked Packaging			*37,50*	*27,*			*50*
	Safety							*3,55*
	Simulation			*16,17,28,44,45, 48*	*1,2,45,6,48*	*49*		*6,9,31,58,64, 65*
	Model validation			*30,60*	*30,55,5453, 52,51,57*		*47*	*56,60,61,62 55,54,47*

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МЕРЕЊЕ УТИЦАЈА МЕХАНИЧКИХ И КЛИМАТСКИХ УСЛОВАНА ПАЛЕТЕ ПРОИЗВОДА ПРИ РУКОВАЊУ И ТРАНСПОРТУ

К.Фрагаса, И. Макалусо, М. Вакари, Ђ. Луђизано

Руковање и транспорт могу се претворити у катастрофално искуство за интегритет робе и производа. Ова чињеница је подстакла пажњу произвођача у правцу развоја мера у циљу повећања интегритета. Истовремено, за добијање заиста ефикасног решења, услови заштите животне средине и ниво стреса који могу да делују на ове производе током путу од произвођача до крајњег купца морају бити истражени. Овај рад илуструје неке од најважнијих метода и искустава за праћење палета производа.