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Condition monitoring of dynamic system for packaging industry

Alberto Chiarello [1], Aldo Rossi [1], Nicola Pozzan [2]

[1] *Department of Management and Engineering, University of Padova, Vicenza, Italy 36100*
[2] *Ecor International S.p.A., Schio (Vicenza), Italy 36015*

alberto.chiarello.3@phd.unipd.it

Abstract
This work arises from the requirement to monitor the packages separation downstream of the packaging machine: the asepticity of the content could be compromised by a non-compliant splitting system. The main effects that influence the system functionality are the impact and the dynamic stress.
To emulate the real process, a test rig was designed with multiple stations to collect a larger amount of data. Each of these was sensorized with strain gauge load cells to monitor the dynamic and the impact phenomena that occur. Also the oil temperature and the pressures in the hydraulic implant were kept under control.
The force curves have allowed to analyse different events/effects: the stiffness of the system, the force required for the separation of the material, the progressive obstruction on the rear side of the stations due to material scraps.
The acquired parameters of the hydraulic system have shown an interesting response in terms of rapidity of the mechanical system: the more the temperature increases during the day, the lower the force delay in reference to the control signal. This information has permitted to establish the optimal working condition, maintaining the operating oil temperature around 40 °C.
All the logged data have contributed to assess the state of the system, advising when a maintenance operation has to be performed. Some warning events that could be detected are the accumulated material scraps that enhance the impact effects, an anomalous stiffness of the components or a damaged tool that causes higher force peaks.
The condition monitoring obtained allows to schedule only required service operations, ensuring the quality of the packaging separation interface and reducing the maintenance costs.

Condition monitoring, dynamic, impact

1. Introduction

The functions of packaging are to contain, preserve, protect and dispense the products. It is selected taking into account the protection required, and the compatibility with the content.

During the entire packaging process, the integrity of the packaging material has to be guaranteed in order to maintain its functionality.

The packets separation affects in a significant way these properties: the division interface mustn't allow the interaction between the content and the external environment. This process was investigated to increase the packaging quality and therefore of the product.

The information gathered in the research has been used to implement a condition monitoring (CM) system that allows to monitor the process in order to ensure a constant quality.

2. Splitting station

Before the packaging separation, a continuous stream of packaging material wraps up the products. The packets division is performed by a splitting tool driven by an actuator.

To prevent the material from bending under the action of the tool, it is locked between two clamps. After the actuation, the return to the initial position is mechanically facilitated. The station schematization is shown in Figure 1.

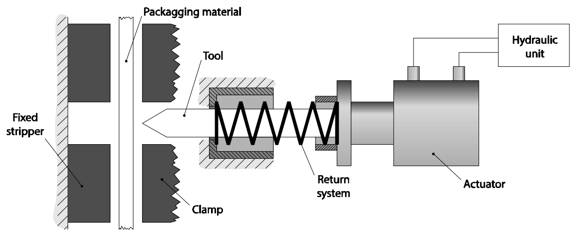

Figure 1. Splitting station and its components.

The present research has been mainly focused on the splitting tool which significantly affects the packet separation process, but also the status of other components has been monitored.

3. Experimental apparatus

To properly investigate the splitting station behaviour, the real machine process was emulated in a test rig with multiple splitting stations in order to collect a larger amount of data. Each of these was equipped with a load cell to measure the force that the splitting tool perceived. Also the hydraulic system was monitored by pressure and temperature sensors. To ensure that the test rig properly emulated the real machine process, also the vibratory behaviour was monitored by an accelerometer.

This configuration was evaluated to satisfy also the subsequent implementation of a CM system.

4. Acquired curves

For the purpose of this research, the most significant parameter was the force acting on the tool. Analysing these curves, the splitting operation has been divided in different events, each of them with specific features: the start and the end of the actuation, the material separation and the related force peak, the force at the end stroke of the actuator, the load and the unload of the return system.

Relying on these attributes it was possible to evaluate the working condition and the state of the components comparing with those defined during the standard cycle.

4.1. Force peaks evolution

The force peaks were monitored to evaluate the evolution of the tool state. A progressive degradation of this component led to an increasing value of the force required to the actuator to divide the packets.

The high performance of the material selected for the splitting tool allowed a minimum degradation even after several thousand cycles.

4.2. End stroke force evolution

One of the main cause of imperfect division of the packets was due to the accumulation of packaging material scraps in the gap between the strippers.

This event could be detected in the early stages before the efficiency of the splitting process was decreased thanks to the monitoring of the end stroke force. In fact, the scraps reduced the stroke of the tool, hence the return component was more compressed and the measured force was increased.

This information has been used with the CM approach to request a cleaning operation.

4.3. Return system preload evolution

The return system had been studied in a previous test to evaluate its lifetime. With the sensor configuration evaluated for the splitting system, a similar investigation was implemented.

The force curve presented a plateau at the beginning and at the end of the cycle that represented the preload of the return system. This value was decreased if the related component had a loss of stiffness.

With appropriate algorithms this measurement was introduced in the CM system to show the return component state.

4.4. Oil temperature effect

The measurements on the hydraulic implant showed an interesting relationship between the oil temperature and the response delay of the mechanical system (Figure 2): the more the temperature increased during the working day, the lower the force delay. This was due to the greater oil fluidity that increased the mechanical response of the splitting system.
Thanks to this result the optimal oil temperature was defined around 40 °C.

4.5. Vibration energy evolution

The variations of the accelerometer signal intensity and its characteristic frequencies are function of tool wear. [1]

Weller *et al.* [2] observed that worn cutting edges produced high-frequency vibration energy that was not observed in the sharp cutting tool noise.

Correlating these assumptions with the trends of the force peaks, it was possible to monitor the splitting tool wear.

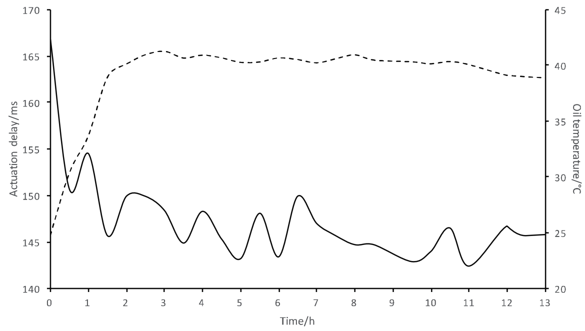

Figure 2. Actuation delay trend (solid) in reference to oil temperature (dashed).

5. Condition monitoring implementation

The above-mentioned parameters were used to implement a reliable CM system which allowed to monitor constantly the state of the system components. Several warnings were implemented to notify in advance the operators of any problems associated with the splitting station.

To obtain a flexible alarm definition the thresholds were defined taking in consideration the mean value (x_{avg}) of the evaluated feature and its standard deviation (σ) by the formula:

$$T = x_{avg} \pm k \cdot \sigma$$

with $k = 1, 2, \dots n$ an appropriate coefficient to define the region within which the parameter should normally vary. [3]

6. Conclusions

The required quality of the packets division downstream of the packaging machine has led to investigate the splitting system. Several sensors were used to monitor the forces applied on the tool and other process parameters such as the oil temperature and its pressure.

Thanks to these acquisition a CM system was implemented based on the trends of some features: the increase of the force peaks value and of the vibration energy were linked to the degradation of the splitting tool, as well as the end stroke force variation was related to the stack of packaging material scraps.

The state of the return system component was deduced by the evolution of its preload found in the force curve.

During this research also the relationship between the oil temperature and the response delay of the mechanical system was assess, and the optimal value was defined around 40 °C.

The CM is going to be improved with the alarm management implementing specific controls on the machine parameters to ensure the quality and safety of the process.

References

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