Project review: elastic decoupling of a large roller grinder

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ABSTRACT

Getzner as a manufacturer of polyurethane-material is involved in a broad variety of projects for elastic decoupling of machines. In this conference-contribution a detailed insight-view of a particular project is given.

The project is about the elastic decoupling of a roller grinder. The roller grinder is situated in the vicinity of other machines; so the machine is exposed to high levels of shock and vibrations. To ensure the accuracy of this high-precision-machine over the total service life a passive vibration protection with polyurethane-bearings was requested. Studies were performed and a solution with discrete polyurethane-bearings was suggested. This solution was approved by the customer and installed in April 2015. The background of the studies will be presented including explanations of the distinctive features of non-linear polyurethane-material. Recommendations for handling and processability of the material will be given. Finally the constructional execution of the decoupling will be introduced.

INTRODUCTION

Dynamic forces caused by operation of machines or carrying out forklift-work etc. inevitably occur. They cause oscillations on foundation and machine and may have negative influence on the production-processes (e.g. reduced accuracy, increased mechanical wear etc.).

With elastic decoupling an efficient protection measure exists. This vibration isolation can be realized by using polyurethane (PUR). This material fullfills all required characteristics for this application [1].

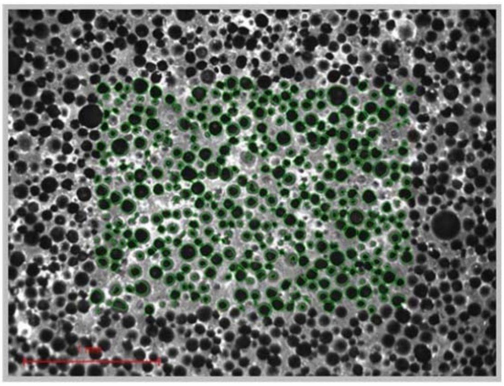
In the following PUR with its material-characteristics, the elastic application as its application and a realised project is explained.

POLYURETHANE MATERIAL (PUR)

Chemistry

PUR is a polymer material. By chemical reaction (poly-addition) the two petroleum-based components Polyol and Isocyanate react to PUR.

In the production-process the cavities are controlled very accurately. Cavities are gametes for the cell-structure in the PUR-foam and therefore responsible for the mechanical characteristics. PUR-material with mixed-cell and with closed-cell-structure exist (Getzner-brand-names Sylomer® and Sylodyn®; see figure 1).



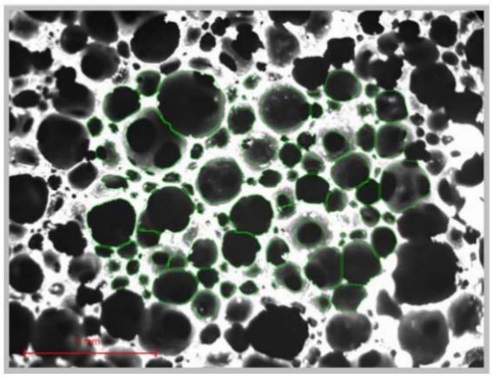


Figure 1: PUR with closed cell structure (left) and mixed cell structure (right)

With the appropriate formulation (reaction mixture, auxiliary components) the mechanical characteristics of PUR can be controlled precisely.

Characteristics

Load-Bearing-Capacity:
Materials have to withstand the static loads for a long time. For mechanical elements this means that no structural damages happen and the long-term-deflection (so-called "creeping") stays within certain parameters. If the load-bearing-capacity of the material is not exceeded the deflection is less than 20% of the thickness after 10 years of operation. This load-bearing-capacity is also named as "static-load-limit".
Typically PUR have a load-bearing-capacity up to 6N/mm^2 [2].

Stiffness:
Stiffness k as a pad-characteristic depends on dimensions of the pad (area A and thickness t) as well as of Young's Modulus E of the pad-material. See formula 1.

$$k = \frac{E \cdot A}{t} \quad (1)$$

For PUR the Young’s Modulus mainly depends on load and frequency. See a typical behaviour in figure 2.

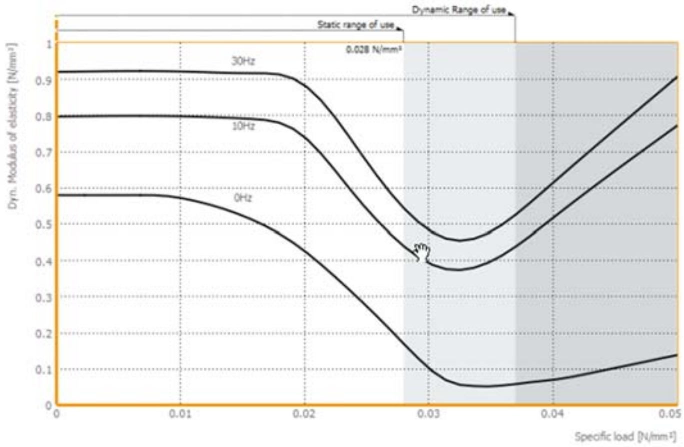


Figure 2: Typical Young’s Modulus of PUR

Following formula 1 to achieve soft pads (which is benificial for the effect of vibration isolation) a low Young’s Modulus or a high thickness is required. The Young’s Modulus of PUR is low in the area where the load-deflection-diagram (see figure 3) shows a degressive behaviour (close to the static-load-limit). Therewith the non-linear behaviour of PUR can be used very well for vibration isolation.

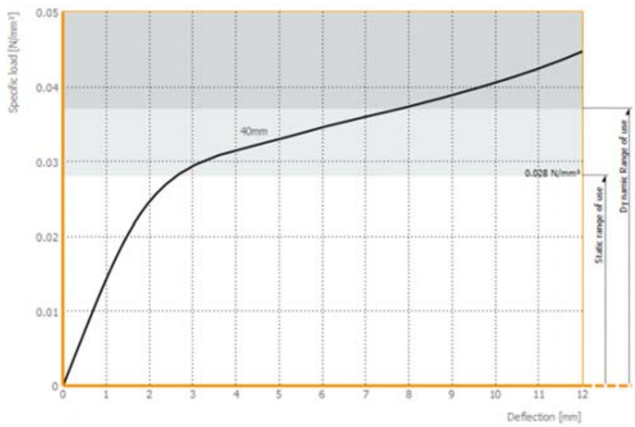


Figure 3: Typical Load-deflection-diagram of PUR

Damping:
Material-damping is a term of structural mechanics. All materials show decreasing oscillation-amplitudes over time. This decrease bases on material properties and can be described over the so-called loss-factor η. With PUR loss-factors range from 0,08 to 0,5 which is from 0,04 to 0,25 in terms of Lehr damping factor [2].

ELASTIC DECOUPLING

Dimensioning and Design

For the elastic decoupling a complete separation from the machine to the surrounding is done. Therefore a soft material like PUR can be used. PUR shows best parameters like load-bearing-capacity or appropriate stiffness and damping for reducing the level of vibrations [1].

For a long-term-stability the elastomer material needs to withstand the occuring compression stress caused by static loads (see characteristic load-bearing-capacity). To achieve the correct dynamic behaviour the stiffness and natural frequency has to be determined according to the excitation.

Generally elastic decoupling can be done with or without foundation (figure 4). Having the elastic layer below the foundation is preferred because the structural vibrations of the foundations are in a higher range. Secondly the vibration amplitudes can be reduced. Therefore literature recommends additional mass – see e.g. [3]

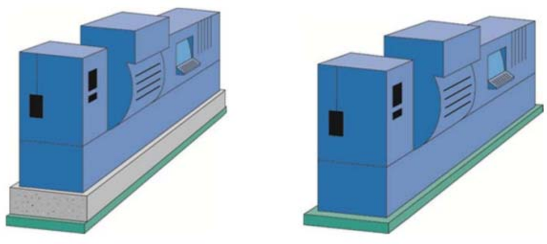


Figure 4: Design of elastic decoupling with and without foundation

For high-performing elastic decoupling discrete bearings are used instead of full-surface-solutions (see figure 5). Full-surface-solutions show advantages during construction because they can be used as lost formwork. But for discrete pads the pad-dimensions can be choosen according to the optimal utilization thus achieving high performance. For constructional execution of discrete pads is more elaborate on construction sites.

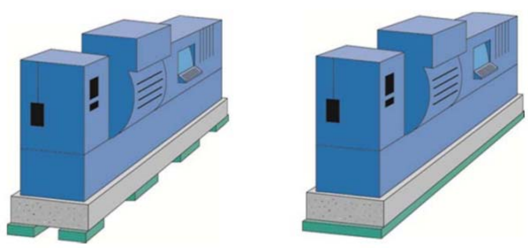


Figure 5: Design of elastic decoupling with discrete bearing and with full-surface

Mechanism of Action

Elastic decoupling can be modeled with a harmonic oscillator (see figure 6).

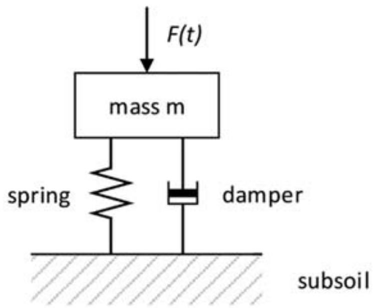


Figure 6: Physical model of a harmonic oscillator

The reduction of vibrations ("vibration isolation") bases on the physical principle of compensation of mass-forces.

Machine with its dynamic forces is modeled with $F_{(t)}$, the PUR is represented by spring and damping-characteristics (stiffness k and loss-factor η).

This harmonic oscillator has the vertical natural frequency f_0 as a characteristic parameter which can be calculated with mass m and stiffness k (formula 2):

$$f_0 = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{k}{m}} \qquad (2)$$

For the transmission-function of a harmonic oscillator following equation can be developed (formula 3):

$$L_{(f)} = 20 \cdot log \sqrt{\frac{1+\eta^2 \cdot \left(\frac{f}{f_0}\right)^2}{\left(1-\left(\frac{f}{f_0}\right)^2\right)^2 + \eta^2 \cdot \left(\frac{f}{f_0}\right)^2}} \qquad (3)$$

Showing this equation in logarithmic scale and standardized to the natural frequency results in figure 7:

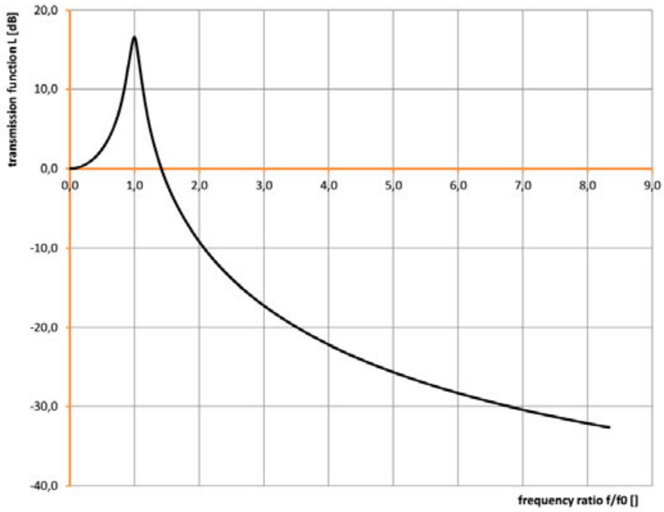


Figure 7: Transmission function of a harmonic oscillator

In this transmission-function three different areas can be seen:

- amplification of signal where $f_e/f_0 < \sqrt{2}$
- resonance of signal where $f_e/f_0 = 1$
- no change of signal where $f_e/f_0 = \sqrt{2}$
- reduction (isolation) of signal where $f_e/f_0 > \sqrt{2}$

Generally speaking: with a given excitation frequency f_e reducing the natural frequency f_0 (thus decrease stiffness) the vibration-isolation is increased.
Typically the natural frequency is 1/3 to 1/5 of the excitation frequency to achieve degree of isolation of 80% to 90% [4].

PROJECT ROLLER GRINDER

Initial Position

For modern paper production calender rolls with excellent precision (accuracy in terms of form and shape) are important. For the finishing-process of these rolls a roller-grinder is used.

At a Valmet-plant in Cernay (France) rolls up to 2.5m of diameter and up to 12m of length (max. weight 90to) can be processed with accuracy of ± 3µm over the total length of the rolls.

The roller grinder rests on a deep-seated foundation-block with dimensions 17m x 4.6m in depth 2.5m (foundation-weight approx. 490to).

Machine-masses are as follows:

Table 1: Machine-mass

Component:	Weight:
Motor	5.0to
Headstock (gear box)	7.5to
Bed of workpiece A and B	16.0to
Bearing pedestals	5.0to
Bed of carriage	43.0to
Carriage	6.5to
Workpiece	90.0to
Total	173.0to

Calculation Approach

For this kind of system a high foundation-mass is necessary in order to keep vibration-amplitudes at low values. Here the mass-ratio of 490/173=2.9 is achieved which is a resonable value.

Based on a previous project the customer at first demanded steel-springs with a fundamental vertical frequency of 3Hz. As the constructional complexity would have been very high therewith alternative options were discussed and finally the requirement was restated to a fundamental vertical frequency of <7Hz.

This is possible with PUR-bearings and in this case 66 discrete PUR-pads of type Sylodyn® NE were used. Dimensions of the pads are 390mm x 390mm in thickness 75mm. These pads show a loss-factor of 0.09 (corresponding to 0.045 Lehr damping factor). A fundamental vertical frequency of 6.0Hz was achieved.

With the comparable small moving mass to the high non-moving mass a change of the center of gravity due to the workpiece-movement is not relevant.

For the calculation a mathematical rigid-body-model with six degrees of freedom (three rotational and three translational) was used. Based on the stiffness (dynamic stiffness-matrix of all elastomer bearings) and on the masses (mass-matrix of the overall system; transformed into the center of gravity with orientation to the inertia principal axis) the eigenfrequencies of the system were calculated.

Vibration amplitudes were evaluated by an external consultant.

Constructional Approach

Solutions with a full-surface-elastomer typically show natural frequencies >10Hz (depending on thickness and utilization-value). So for this project with requirement <7Hz a discrete-solution was necessary. Arrangement of the discrete pads was done according to an installation drawing (installation see figure 8). In installation-instructions [5] a smooth and plane surface is required.

Figure 8: Discrete elastomer pads in the foundation-pit

For concreting (shuttering) a 25mm steel-plate was used. The steel-plates were positioned on top of the elastomer-bearings and welded together at the joints. By doing so the air-gap between the pads is assured and this steel-plates can be as shuttering. See figure 9.

Figure 9: Welded steel plates for shutting

An elastic decoupling to the full extent (including bottom and sides) is essential for the functionality. An air-gap at the sides is one option therefore. This normally is a very elaborate measure. But for this project it was done like the following: A cardboard-product was attached to the sides of the foundation-pit (see figure 10). During concreting of the foundation-block this cardboard can resist the concrete-pressure. And after the maturation of the foundation-block the cardboard was watered and thus showing no influence to the total system anymore. This is a very powerful approach for realizing lateral air-gaps.

Figure 10: cardboard lateral gap

FACT BOX

Table 2: Fact box

Machine:	roller grinder
Machine weight:	173to
Foundation:	17m x 4,6m with depth 2,5m
Foundation weight:	490to
Vibration isolation:	discrete polyurethane-bearings (type Sylodyn® NE in thickness 75mm)
Commissioned:	September 2017

CONCLUSION

With a recommended strong cooperation between plant-operator, material-provider and planning consultant effective solutions can be created [6].

The requirements are defined by the plant-operator, material-know-how is provided by the material-provider and the forecast-analysis and verification is done by the planning-consultant.

This way of collaborative working has been successfully implemented in this project.

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