Experiences of a Polyurethane-Manufacturer with the Elastic Decoupling of Machines

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Summary
Polyurethane is an excellent material for elastic decoupling of machines. Getzner Werkstoffe as a manufacturer is involved in a broad variety of such projects.
This paper is an introduction to the material itself, to the constructional execution of the decoupling and to the success of the reduction measure. The distinctive features of polyurethanes are explained as well as recommendations for handling and processability are given. Procedures for dimensioning of elastic bearings and different ways of constructional execution are illustrated.

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1. Introduction

During operation of machines dynamic forces occur. They are the reason for vibrations on foundation and machine. These vibrations are transferred to the surroundings as structure bourne noise and are perceptible there as vibrations or as secondary airborne noise. Due to that human beings and machines have to be protected.

For an efficient protection a vibration isolation in the form of an elastic decoupling is a commonly used measure. In doing so the machine is separated completly from the surrounding with elastic material. Proper elements should feature elastic and damping characteristics. [1]

In the following polyurethane (PUR) as a material for vibration isolation as well as it's application is explained.

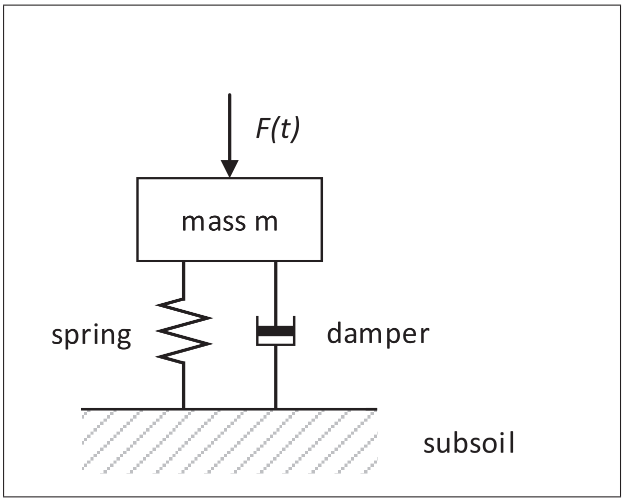

Figure 1. Harmonic oscillator.

2. Elastic Decoupling

2.1. Mechanism of Action

Vibration-isolating effect of an elastic bearing bases on the physical principle of a compensation of mass-forces (so-called "harmonic oscillator" – see figure 1).

Dynamic forces of the machine are shown with force F_t, machine-foundation is represented with mass m; elastic decoupling is shown with a spring-damping-unit (stiffness k and damping η). Generally a stiff subsoil and rigid bodies of the system are assumed (no relative movement nor structural vibrations). Furthermore only the stationary condition caused by an harmonic excitation is considered.

With the mass m and the dynamic stiffness k' of the spring the vertical natural frequency f_0 can be calculated as a characteristic parameter of the system with the following equation:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k'}{m}}. \tag{1}$$

With polyurethane-material natural frequencies as los as 6Hz are applicable. For lower natural frequencies it's not economic to use polyurethane – there are other products available (steel springs, air-springs etc.).

Ratio of input- and output-amplitude is called transmission function L (amplitude-frequency re-

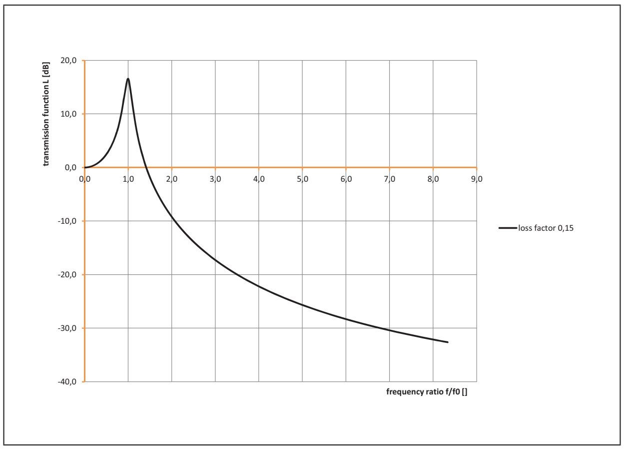

Figure 2. Transmission function.

sponse). For a harmonic oscillator it can be calculated with natural frequency f_0 and damping η as follows:

$$L(f) = 20 \cdot \sqrt{\frac{1 + \eta^2 \cdot \left(\frac{f}{f_0}\right)^2}{\left(1 - \left(\frac{f}{f_0}\right)^2\right)^2 + \eta^2 \cdot \left(\frac{f}{f_0}\right)^2}}. \quad (2)$$

Drawn over the frequency-spectrum in logarithmic scale and standardized to the natural frequency figure 2 results.

In this transmission function (figure 2) different areas can be obtained:

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

Common frequency-ratios are 3 to 5; for higher ratios big effort has to be made for relatively low additional value (cost-benefit-analysis).

2.2. Dimensioning

First of all the elastic material has to withstand the occuring compression stress caused by the static loads ("loading capacity" see section 3.2.1).

In the second step the efficiency of vibration isolation has to be evaluated. As shown in the previous section the natural frequency is a relevant parameter and can be calculated with equation 1. Mass m results of machine and foundation and dynamic stiffness k' of the elastic bearing can be calculated with dynamic Young's Modulus E', bearing-area A and thickness of the bearing t:

$$k' = \frac{E' \cdot A}{t}. \quad (3)$$

Thus a statement to vibration isolation ("degree of isolation") can be done with the transmission function (equation 2).

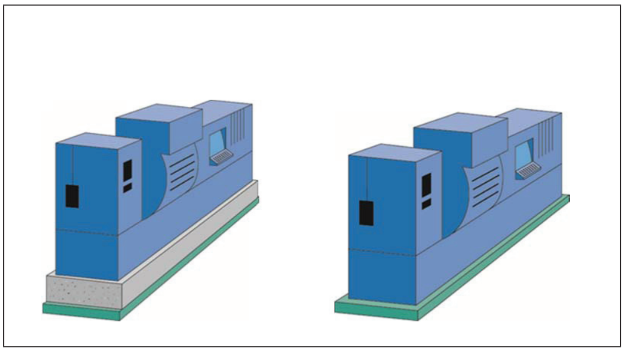

Figure 3. Design with and without foundation.

The non-linearity of polyurethane is very positive for the vibration-isolation, but for calculation and modelling a few points have to be taken into account:

- providing a Poisson-ratio for the relation of stress and elongation is very limited
- rough estimation of the natural frequency via the deflection is not allowed
- good material-models with lots of parameters for FEM (finite element analysis) are available, but specifying all these is very complex

At Getzner datasheets are edited in a way, that the user can conduct these calculations by himself. Furthermore an online-tool is offered on the website `http://www.getzner.com` or as an app in Android-/iTunes-store.

2.3. Design of elastic decoupling

Generally elastic decoupling can be realized with or without foundation - see figure 3. A solid basement is preferred. It results in a better distribution of the mass and the structural vibrations of the foundation are in a higher range. Vibration amplitudes can be reduced (system is "calmed"). Recommendations for the mass-ratios of machine to foundation are available. [2]

Furthermore elastic bearing can be implemented discretely (point-bearings) or full-surface – see figure 4: Full-surface-bearing offers advantages during construction as the elastic bearings can be used as lost formwork. Discrete bearings are more elaborate at the construction sites (use of pre-fabricated-plates). In exchange the discrete bearings can be realized in a way that the dimensions length and width are done exactly according to the occuring loads and so the capacity of the bearings is optimal. Therewith very deep natural frequencies can be achieved (see section 3.2.2).

Stiff connections of the decoupled mass with the subsoil have to be avoided ("noise bridges"). There has to be taken care that also the lateral gap is done elastically. For a correct installation a supervision on site is recommended.

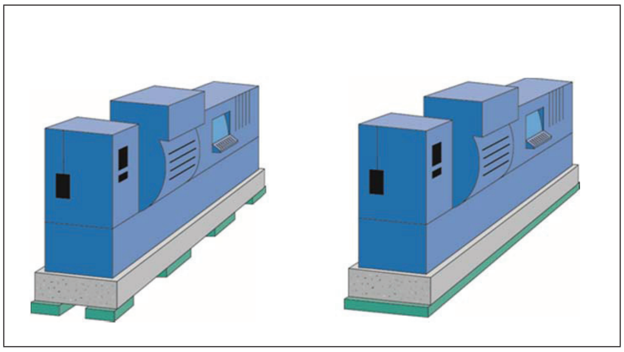

Figure 4. Discrete and full-surface bearing below a foundation.

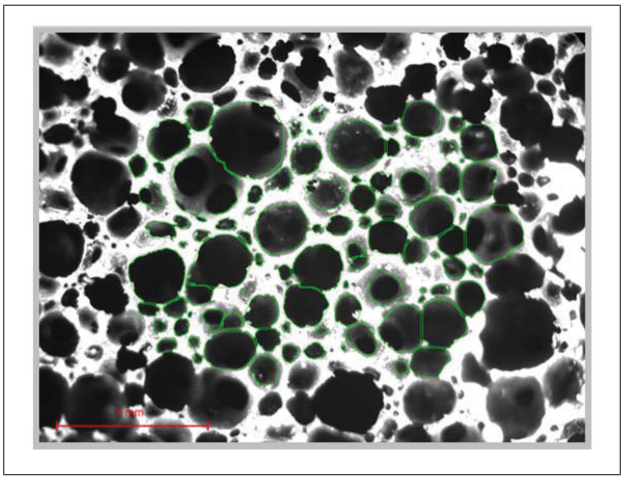

Figure 5. PUR with open cells.

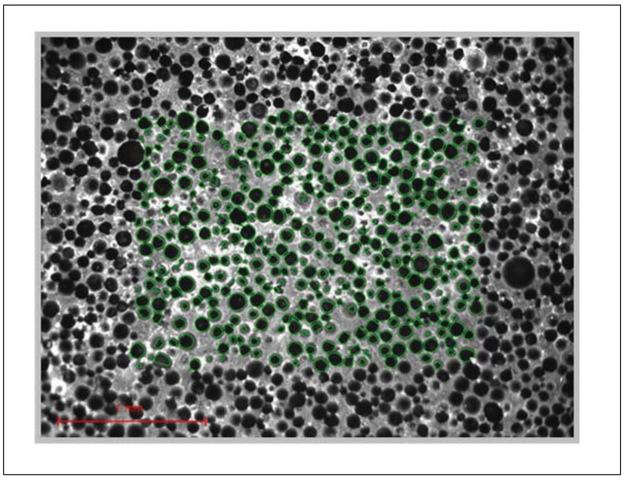

Figure 6. PUR with closed cells.

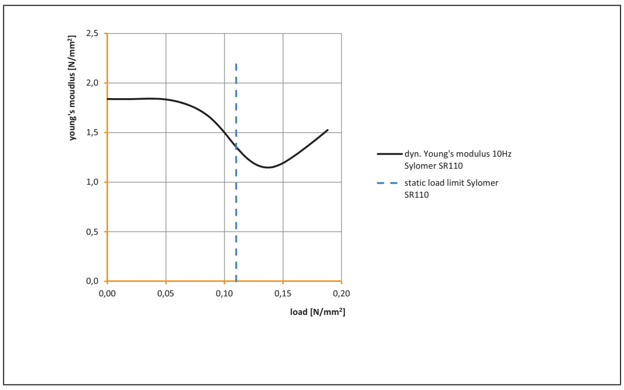

Figure 7. Young's Modulus of Sylomer® SR110.

3. Polyurethane Material (PUR)

3.1. Chemistry

For producing PUR in rolls a reaction mixture out of isocyanate and polyol is applied out of a mixing head on a continuously moving carrier tape. Caused by chemical crosslinking with additional foaming agents the mixture foams up and PUR develops. Cell-structure, density and other parameters can be regulated precisely with the reaction mixture. Therefore also the mechanical properties like stiffness, loading-capacity and damping arise. Enlarged views of the cell-structure of PUR can be seen in figure 5 and in figure 6.

3.2. Specifications

In the following only the mechanical parameters which are relevant for a vibration isolation are mentioned. Of course other requirements for elastic material exist (chemical resistancy, formal permits etc.). Those have to be taken in account for each project as well.

3.2.1. Loading capacity

Materials for vibration isolation have to withstand the static loads for a long time without any damage and without immoderate increase of the deflection over the whole lifetime (see section 2.2).

By changing the chemical recipe the loading-capacity of PUR can be varied precisely. Depending on the density PUR has a permissible compression stress from $0.01\,\frac{\mathrm{N}}{\mathrm{cm}^2}$ to $6\,\frac{\mathrm{N}}{\mathrm{cm}^2}$. The term "static load limit" is used herefore (see [3]).

Dynamic loads or load-peaks can be significantly higher without damaging the material (no destruction of the cell-structure nor change of parameters).

It is important that the material withstands the loads and that the load-point is chosen optimally (see section 3.2.2).

3.2.2. Stiffness

Stiffness of the elastic bearing determines the natural frequency of a system (thus determines the efficiency of the vibration isolation - see also section 2.1).

It is also obvious that a low Young's Modulus is beneficial for a deep natural frequency. That's the case for PUR-materials in their optimal operating load-range (near the so-called "static load limit"). For material working exactly at the static load limit one speaks of a "utilisation value" or "capacity" of 100%.

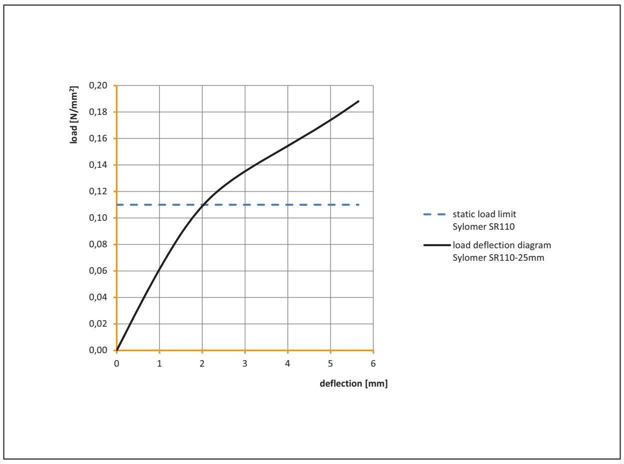

Figure 8. Load deflection diagram of Sylomer® SR110.

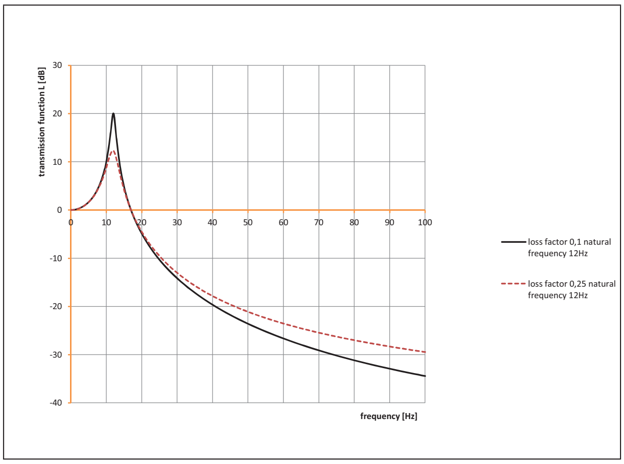

Figure 9. Variation of damping - transmission function.

Young's Modulus (progression and absolute value) depends on the chemical recipe and density: e.g. for PUR with a low density the value for the dynamic (10Hz) young's modulus is in a range of $0.15\,\frac{\mathrm{N}}{\mathrm{cm}^2}$ to $0.6\,\frac{\mathrm{N}}{\mathrm{cm}^2}$ and for PUR with a high density the range is from $10\,\frac{\mathrm{N}}{\mathrm{cm}^2}$ to $12\,\frac{\mathrm{N}}{\mathrm{cm}^2}$.

Materials with a lower Young's Modulus do have a lower loading capacity (see section 3.2.1). If a a higher-density-material with a higher young's modulus has to be used (due to higher loads) a low natural frequency can be achieved with an increased thickness of the pad (see equation 3: stiffness is like reciprocal to the thickness of the pad).

Another approach for the explanation of the optimal load point works over the load-deflection-diagram. The tangent of the load-deflection-diagram has a low gradient in the optimal load-point (see figure 8). That means the material reacts "soft" in this load-point and provides a low natural frequency.

So the non-linear behaviour of PUR is excellent for a vibration isolation.

3.2.3. Damping

Damping can be characterized with the so-called loss-factor (no dimension). The value depends on the chemical recipe and goes for open-cell PUR from 0.11 to 0.25 and for closed-cell PUR from 0.07 to 0.10. Damping has effect on the progression of the transmission-function (amplification at resonance and gradient of the curve in isolation-area – see figure 9).

Adequate damping is essential for a correct dimensioning. During run-up and run-down of the machine the resonance-area is passed. Depending on the speed of this "passing" the damping has to be adjusted in a way that the amplitudes do not exceed the given limits.

3.3. Handling

PUR can be produced in different dimensions (up to rolls in width 1,5m and length 35m with thickness 4mm up to 60mm). For higher thicknesses several layers of the material can be glued. Then the material can be considered as homogeneous.

PUR can be processed very well. With the proper machinery it can be split, it can be stamped or it can be processed with water-jet. Therefore the elastic bearings can be realized in nearly all dimensions.

The product can be delivered to the construction site in pre-cut shapes, pallets (pallet-size 1,5m x 1,2m) or rolls (1,5m width and 3m length). Depending on the density PUR can be cut with cutting-knife or circular-saw very easily. For installation no heavy equipment is necessary. Identification of the different materials is easy: each type has specific colors and all bearings are equipped with a label (length, charge, ID, . . .).

So that no concrete milk leaks through, all connection points have to be done thoroughly and have to be masked with a tape. Several layers can easily be stacked but it is important that the rolls are positioned with an offset. Therefore big areas can be equipped with PUR in a very short time.

For full-surface-applications no glueing of the mats to the subsoil is normally needed.

PUR can be glued with the appropriate adhesive on different contact-partners (to steel, to concrete, . . .). When using contact-adhesive the very fast curing-time has to be considered: a later positioning of the mat is not possible anymore. On the other side a fixation of the mat is necessary when a two-component-adhesive is used.

For special applications PUR can be combined very well – e.g. be equipped with a textile mesh. Special coatings are also possible.

Furthermore PUR can be brought into nearly all possible shapes with moulding technology.

4. Projects

Getzner can look back on a lot of different projects. Machines out of most disciplines of mechanical engineering were realized with a PUR-vibration-isolation. Pumps, turbines, HVAC, ... were equipped with polyurethane-materials Sylomer® and Sylodyn® with great success.

The optimal technical and economical solution was executed in due consideration of all the constraints. Getzner chose the material, took over the calculation of the vibration isolation as well as the installation of the material at the construction site.

Case-studies for selected projects are available on the website `http://www.getzner.com`.

5. Conclusion

A cooperation between the plant-operator, the material-provider and the planning consultant is essential for an effective solution. [4]

Plant-operator formulates his requirements with the technical constraints, material-provider provides detailed material-know-how and planning-consultant does the forecast-analysis and the verification of the efficiency.

Only with that strategy a technically correct and economical solution that works well for the whole period of use can be realized for the customer.

References

[1] VDI Verein Deutscher Ingenieure: VDI 20620 - Vibration insulation. D-Düsseldorf, 2007.

[2] H. Dresig, F. Holzweißig: Maschinendynamik. Springer, D-Chemnitz, 2007.

[3] Getzner Werkstoffe GmbH: various datasheets Sylomer® / Sylodyn®. A-Bürs, 2015.

[4] Deutsches Institut für Normung: DIN EN 1299 - Mechanical vibration and shock - Vibration isolation of machines. Berlin, 2009.