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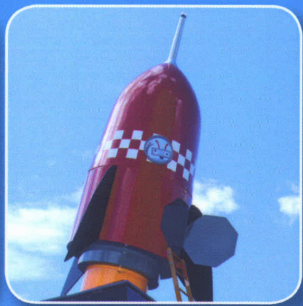

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Polyurethane the perfect vibration isolator

Martin Dietrich

The question of whether or not a product is perfect can be clarified at either marketing or technical level. The statement that a product is perfect can be verified by monitoring the market, since the number of market participants is constantly increasing, after all, they all want to make a profit, and the performance of the material has been acknowledged by the market over the course of the years. However, technical evidence of this obvious fact has been provided during application over the course of many years. The advantages of polyurethane compared to other products are presented below.

Basic principles of vibration isolation

Vibration isolation is understood to be the minimisation of transmission of vibrations (excitation frequency up to 30 Hz) or structure-borne noise (excitation frequency ‹ 30 Hz) from a source of vibration to the surroundings to be protected.

Sources of vibration may include, for example, railway traffic or machines. The basic principles of vibration isolation are usually described and explained on the basis of a single-mass oscillator for vertical translational motion. This idealised and simplified model consists of rigid masses, springs and dampers.

The elastic properties of the vibration isolation element are therefore of crucial significance to determine the effectiveness of vibration isolation.

Besides the static stiffness of the component, which is decisive to ascertain the deformation under static load, the dynamic stiffness is the most important parameter to determine the natural frequency of an oscillatory system.

This natural frequency, i.e. the frequency at which an oscillatory system continues to oscillate freely after one-time excitation, is calculated by the following formula:

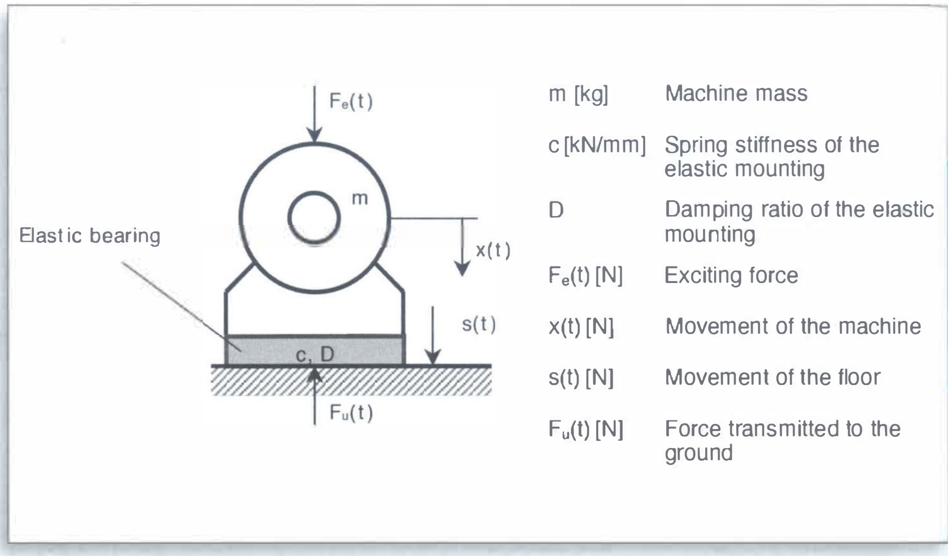


Fig. 1: Single-mass oscillator

$$f_o = \frac{1}{2\pi}\sqrt{\frac{E}{\sigma}} \quad \text{[Hz]}$$

E = dyn e-modulus; σ = specific load

Using the natural frequency and another material parameter, namely the damping of the elastomer, the isolation effect can be determined on the basis of the transmission function.

This transmission function describes the mathematical relationship between the system response and the impact and generally renders a function of the frequency ratio f/fo (excitation frequency/resonant frequency).

This figures (fig.2) shows that an isolation effect is only given at a frequency range of $f/f_o < \sqrt{2}$ vorliegt.

Having explained the parameters that are important for vibration isolation, namely dynamic stiffness and damping, we need to look at some other requirements that are relevant to application.

For long-term effectiveness, the vibration isolation element has to additionally exhibit the properties that are important for the load-bearing capacity, namely static stiffness, creep resistance and fatigue strength. Other parameters, which are usually not that obvious, include the frequency dependence and amplitude dependence of the dynamic properties.

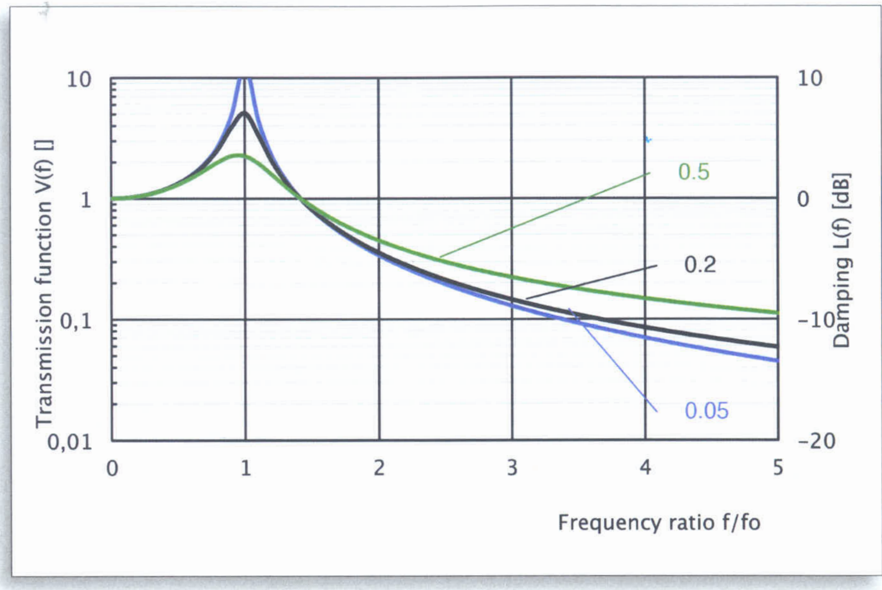


Fig. 2: Transmission function as a function of the frequency ratio

Taking into account the above material requirements, we can start verifying that polyurethane is the perfect vibration isolator. To this end, it is necessary to compare the specific properties of other products used for this application with those of polyurethane.

Alternatives to polyurethane include steel springs, rubber materials, polyurethane-bonded rubber granules (e.g. of used tyres) or polyurethane-bonded material mixtures of cork, rubber, PUR foam and foamed rubber products as well as mineral fibres and thermoplastic materials. A distinction between compact and foamed products is not made here, since merely the presence of specific properties that are relevant to application as a component usually subject to high compression loads is examined.

Among steel springs, helical compression springs are used most commonly. Being almost ideal springs, steel springs permit very low tuning frequencies. This is attributable to the fact that the dynamic stiffness is only slightly higher than the static stiffness, which is why the stiffness ratio ranges just above one.

However, this advantage is at the cost of negligibly small damping effect. If the excitation frequency is unfavourable compared to the tuning frequency, this may in extreme cases cause the entire system to move within the resonance range, leading to what is referred to as a resonance disaster, i.e. the amplification of the displacement amplitude of the source of vibration, resulting in the destruction of the system as a further consequence. This phenomenon can only be prevented by installing additional damping elements and adapting the tuning frequency. In real systems, both vertical and horizontal forces are exerted. Besides a lack of damping effect, helical compression springs are also characterised by low shearing stiffness, which is why shearing forces cause excessive horizontal movements, necessitating the installation of additional springs to stabilise the system.

Another effect with steel springs is that, depending on the thickness of the spring steel, relatively low frequencies are transmitted to the ground via the spring steel, which is why excitation frequencies below 50 Hz already enter the ground without being damped. Moreover, these are always relatively small components, which is why the resulting forces always put excessive local loads on the ground.

Steel springs

Fig. 3 a) Steel spring; 3 b) Spring with integrated elastomer damper; 3 c) Spring assembly with damper and additional damper for higher-frequency vibrations transmitted via the steel helix

Mineral fibres or fibreglass mats

These products are used predominantly for thermal insulation, also serving the purpose of structure-borne noise isolation in many cases. They are available in various stiffness classes and exhibit dynamic stiffening factors of approx. 2 and higher, which means that their dynamic stiffness is twice as high as their static stiffness.

Compared to steel springs, these products already have an advantage, namely that the damping prevents a resonance disaster and, because of their application over a large surface area, the local load on the ground is low. The fact that polyurethane materials (diisocyanates of various compositions) are widely used to connect the individual fibres clearly demonstrates the performance of polyurethane. The fatigue strength of these products is not comparable to that of other materials. Minor local overload instantly leads to damage (breakage of the fibres), but also the application of evenly distributed load combined with dynamic forces sooner or later causes destruction of the fibre structure, which is reflected in increased settlement and loss of the dynamic properties.

Rubber materials – foamed or compact, natural or synthetic

Rubber products of natural rubber and polyisoprene take a special position among rubber materials. They distinguish themselves from other synthetic materials by their dynamic properties, since the dynamic stiffness of these two products per se ranges between 10 and 20%, which is significantly lower than that of other rubber qualities. Conventional products such as EPDM and SBR are also characterised by a stiffness of more than 50%.

However, the dynamic properties are subject to specific framework conditions that are widely unknown or unintentionally neglected. The annex of ISO 18437-1 expressly points out the high amplitude dependence of the dynamic properties of rubber products due to their carbon black content. As a result, low amplitudes of excitation cause significant stiffening of all rubber products, considerably increasing the low stiffening factors mentioned above (Fig. 4). In addition, the frequency dependence (Fig. 8) and the damping dependence also need to be taken into account as factors influencing the dynamic stiffness and the dynamic e-modulus.

Standard rubber materials, including natural rubber, contain a great number of reactive double bonds due to their chemical basic structure, which are never completely transformed during the vulcanisation process and are therefore still found in the finished elastomer.

As a result of ageing processes and environmental influences, the reactions taking place here may cause brittleness, adversely affecting the properties. (Additives can delay this process, but cannot prevent it completely in the long term.) An exception to this is EPDM, because the number of reactive double bonds can be adjusted during the production process to the minimum number required for the specific application and because their arrangement outside the polymer chain prevents any decomposition reactions. (Fig. 5)

Among foamed rubber products, we need to make a distinction between sponge rubber and cellular rubber. Cellular rubber has a closed cellular structure, whereas sponge rubber is a rather open-cell variant. This distinction is important because closed-cell foamed products subject to high compression loads are characterised by significant creep tendency (increase in deformation under load). The fatigue strength and creep resistance required for vibration isolation are therefore limited.

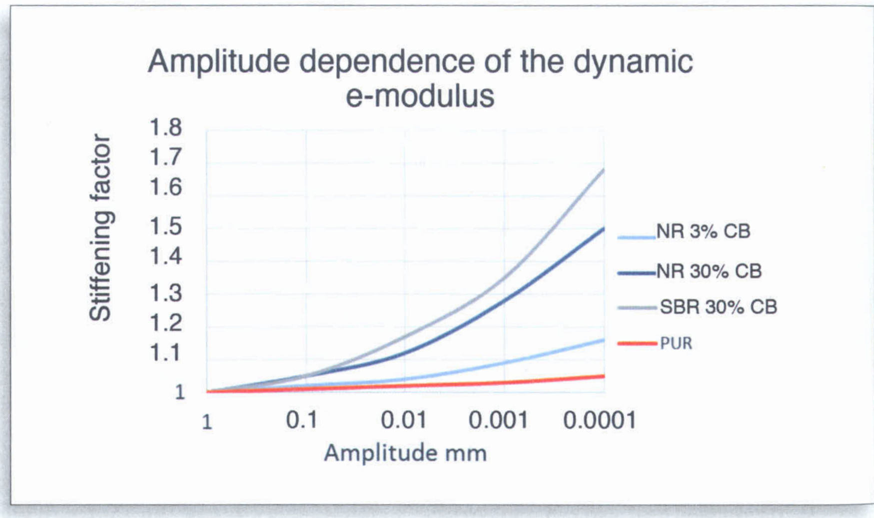


Fig. 4: Amplitude dependence of carbon black-reinforced rubber materials and polyurethane

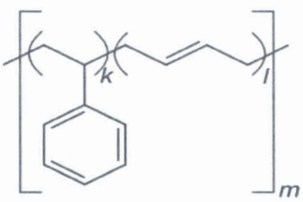
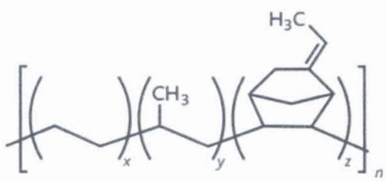


Fig. 5: SBR (Styrene-Butadiene Rubber)



EPDM (Ethylene-Propylene-Diene

Compact rubber products are generally suited for vibration isolation applications and are widely used as composite systems of metal and compact rubber, referred to as rubber-metal elements. The strong connection between metal and partially vulcanised rubber should be mentioned as an advantage. A disadvantage of these elements is their high stiffness, with high local loads being transmitted to the surrounding structure. For this reason, profiled products are offered for applications over a large surface area to achieve the required low dynamic stiffness levels. These systems are highly susceptible to soiling, which may impair effectiveness over the course of time.

Another crucial difference is the deformation behaviour of profiled products of compact materials, which are characterised by the same deformation behaviour as compact materials. Owing to the progressive curve, the dynamic stiffness increases with load, leading to undesirable loss of effectiveness, in particular in what are called multiple-mass oscillators. (Fig. 7)

PUR-bonded granules

(rubber (used tyres); rubber-cork; rubber-PUR foam; flake composites)

A general problem with all above-mentioned products is that they are usually composite systems partly consisting of used materials. Rubber granule mats of used tyres are widely used here. The above statement fully applies to this product group; due to the variations within the residue fraction, the material properties also show significant differences.

The elastic properties of the other composite materials only insignificantly differ from those of the underlying basic materials and a detailed analysis would go beyond the scope of this presentation.

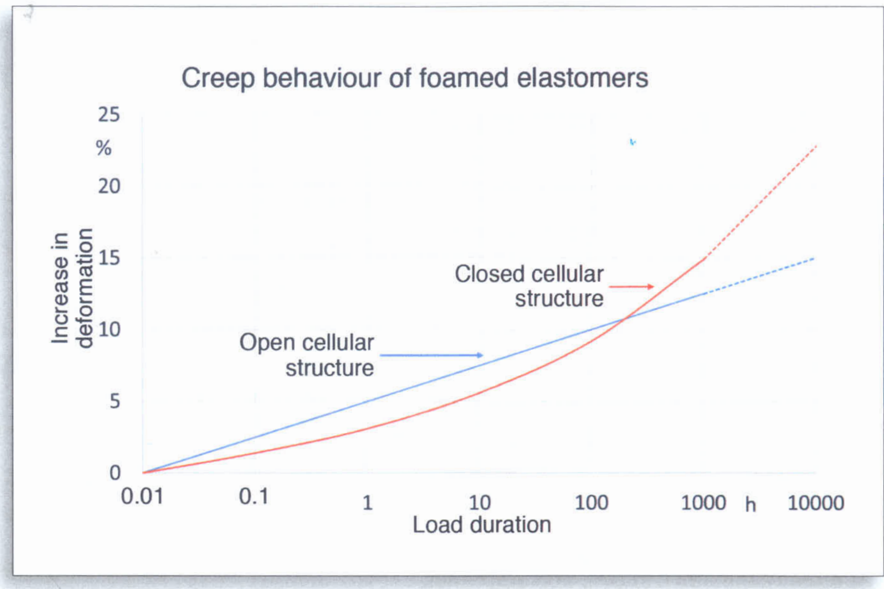


Fig. 6: Creep behaviour of foamed elastomers of comparable density

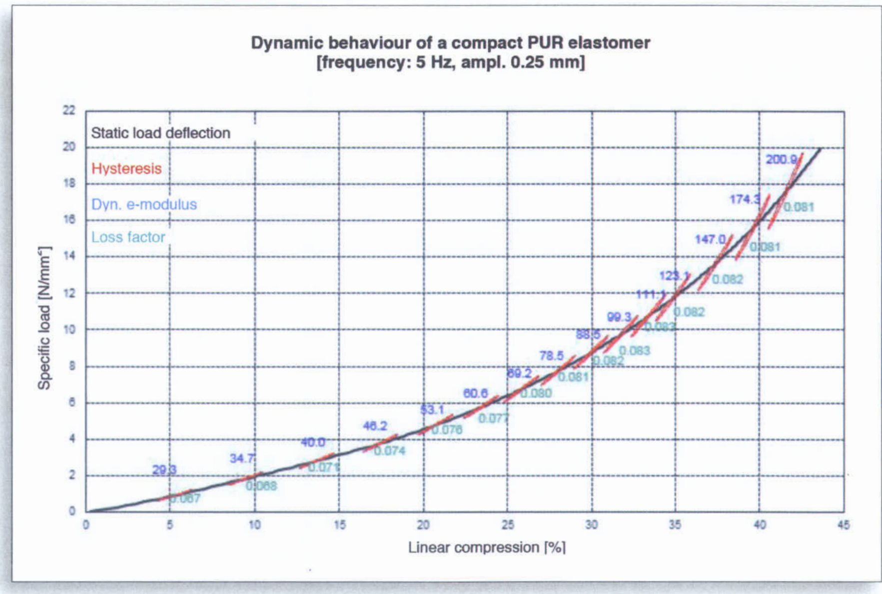


Fig. 7: Elastic properties of a compact material (e.g. PUR)

Polyurethane as the perfect vibration isolator

What makes polyurethane the perfect vibration isolator? Polyurethane can be designed to feature virtually any density and stiffness. This makes the material generally suitable for any conceivable application. Large-scale vibration isolation can always be achieved and the load on the ground is evenly distributed. This makes it possible to prevent high local loads on the ground, which may in extreme cases cause undesirable subsidence of the ground, reducing the effectiveness of vibration isolation as a further consequence.

Polyurethanes are characterised by low (approx. 10%) to medium (50%) dynamic stiffness, depending on the raw materials used. Where necessary, higher stiffening factors are also possible, which would, however, be counterproductive in vibration isolation applications. In contrast to all rubber elastomers, polyurethane materials are characterised by negligible amplitude-dependent variations in stiffness (Fig. 4). This material property also automatically results in a significantly lower level of frequency dependence of the dynamic e-modulus.

As already explained above, polyurethanes always show the same dynamic properties, irrespective of the dynamic loads and the amplitudes of excitation, which is not the case with other elastomer materials. Another advantage of polyurethanes is their chemical structure. The lack of C=C double bonds makes them considerably less susceptible to oxidation than many rubber elastomers. This means that the tendency to brittleness, which can only be improved with additives in rubber materials, is not present.

The excellent ageing stability and fatigue strength is demonstrated not only by corresponding laboratory tests (Fig. 9), but also by many years of experience with and repeated measurements of products in application.

Fig. 10 shows the dynamic properties of a product sample used in the railway sector for about 20 years. Access to the track to take samples was possible during the track closure period as part of the necessary replacement of worn-out rails. The load corresponds to approx. 45 million load cycles; at the underlying axle loads, this yields approx. 750 million load tonnes, which have led to virtually no change in material properties.

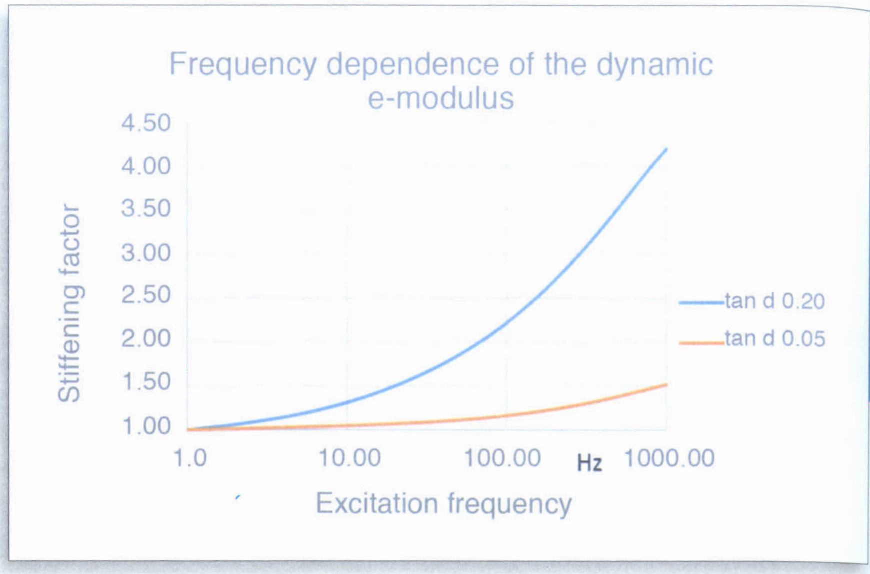


Fig. 8: Frequency dependence as stiffening factor of the dynamic e-modulus

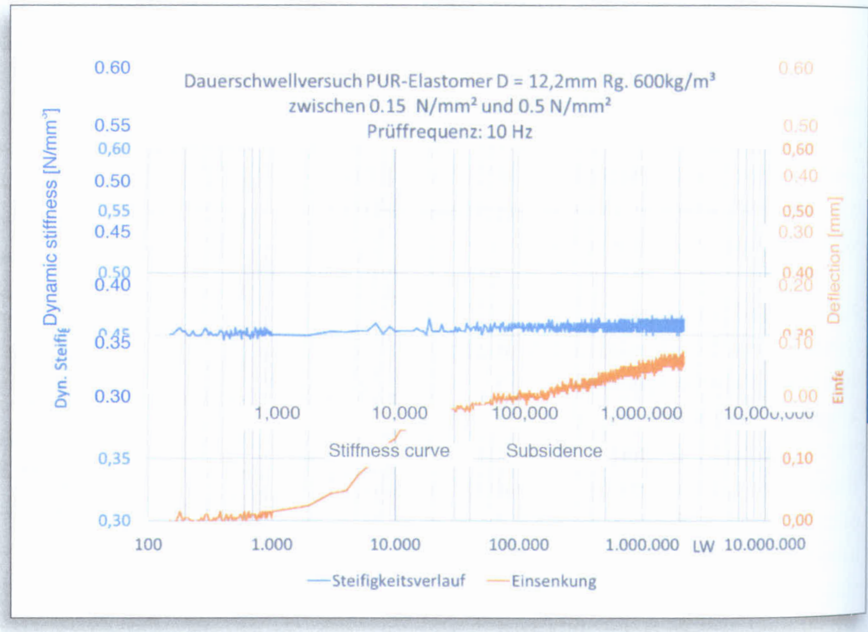


Fig. 9: Fatigue test

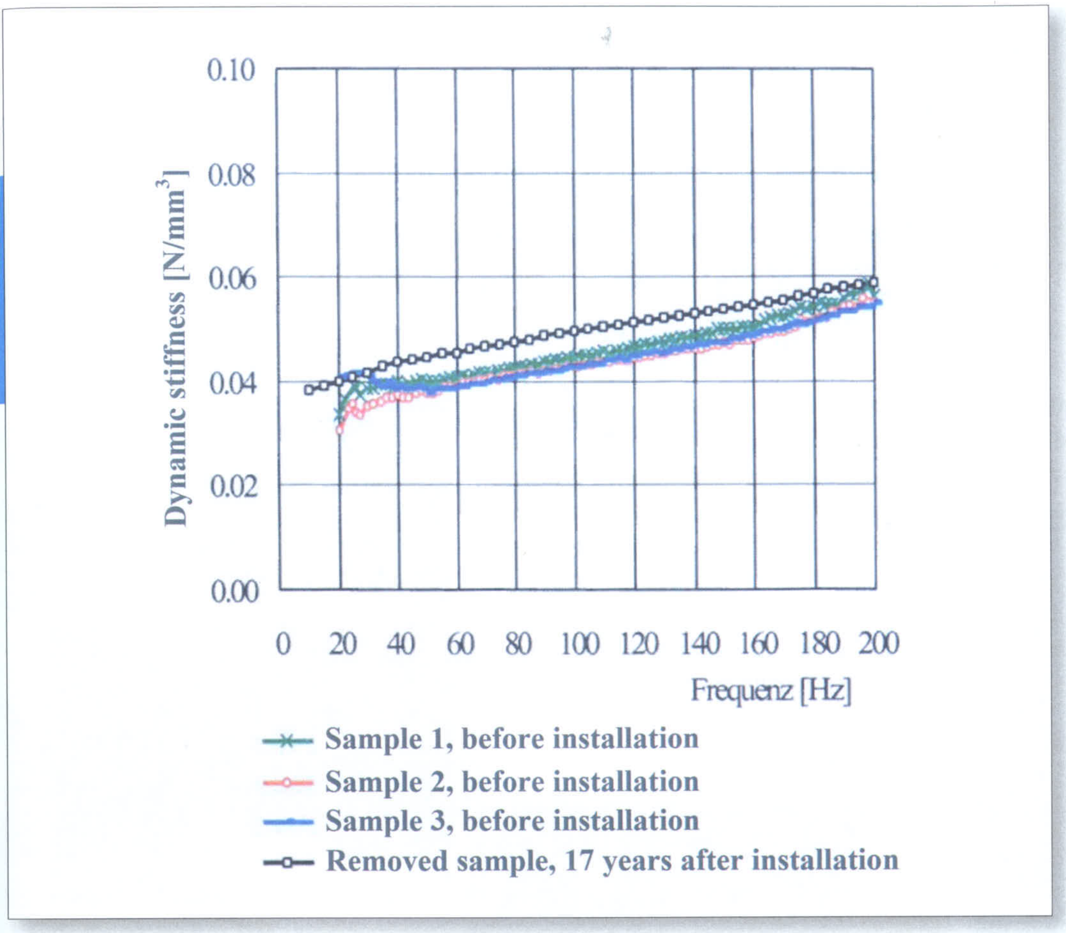


Fig. 10: Hence, polyurethane is the ideal vibration isolator

Summary

Polyurethane is the perfect vibration isolator because this material offers considerably more advantageous properties compared to other components, such as steel springs, rubber products and even composite materials. As a result of the integrated damping, the resonance is expected to increase only slightly compared to conventional steel springs and a resonance disaster is ruled out. Rubber elastomers are characterised by marked amplitude dependence of dynamic stiffness, which is once again significantly increased by the reinforcement material carbon black. The latent presence of double bonds in many rubber elastomers increases their tendency to brittleness. The closed cellular structure of foamed products leads to increased creep and reduced creep resistance. By contrast, polyurethanes exhibit virtually constant dynamic properties as regards both creep resistance and fatigue strength. The frequency and amplitude dependence is significantly lower. Polyurethane is therefore eminently suitable for vibration isolation applications.

BIOGRAPHY

Martin Dietrich

born 1953, studied technical chemistry at the Berlin University of Applied Sciences. He has been working for Getzner Werkstoffe GmbH in the field of research and development since 1977. He was in charge of material development between 1995 and 2015 and is now working as an expert adviser for materials and predevelopment