DYNAMIC PROPERTIES OF MAGNETORHEOLOGIC ELASTOMER

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SUMMARY

Machinery and buildings often have to be protected from vibrations. The needed reduction of dynamic response can be achieved efficiently with semi-active isolation. One way to use semi-active isolation is to install vibration isolators between the base and the object to be protected and control the dynamic properties of these isolators. The advantage of semi-active isolation compared to passive isolation is the adjustability of the system. With adaptive semi-active isolators it is possible to react simultaneously to the changes of the loads and dynamics of the system. This paper describes the laboratory tests and the measurement results of an improved vibration isolator material and an improved adaptive vibration isolator developed by the Technical Research Centre of Finland (VTT). On the basis of the results the presented adaptive material and isolator system is applicable for typical industrial and transportation environments.

INTRODUCTION

During the past two decades the interest in intelligent material based solutions has shown a huge growth. Especially materials, which can respond to the changes in their environment in a very short time are currently developed [1, 2, 3]. In this study the behaviour of the magnetorheological elastomers (MREs) was studied in compressive and also in tension-compressive loading with dynamic loading at passive state and with an increasing magnetic flux density. The dynamic stiffness and the loss factors were calculated on the basis of measured force-displacement loops. For compressive testing in magnetic field, a special coil device was developed so that the load and the magnetic field direction were applied parallel to the chain direction. The dependence of the MR effect on the testing frequency and strain amplitude was studied, considering the possible use of the MREs in low-frequency structural applications with high load and strain. The tunable spring system consisting of the MRE material and the energizing coil device can be used for changing the dynamic stiffness and damping of the structure.

MRE materials used in this test were developed in VTT. Working principle of MR elastomers and processing of the sample materials were described in previous studies [4, 5].

GOALS

Goal of the research was to study the effect of the composition of magnetorheological elastomers in their dynamic and static properties. The pre-load of the elastomer, the amplitude and the frequency of the sinusoidal excitation and also the magnetic flux density were varied in the testing process. In addition, the meaning of the compression and tension-compression loading to the dynamic properties was studied. Tested elastomers had the same volume percent of iron particles and only the hardness of the matrix material was varied. All of the samples were aligned during the curing of the matrix. In the tests there were three different matrix material (in this paper these are called: VTT material no. 1, 2 and 3).

LABORATORY TESTS

The used testing equipment is presented in Figure 1. The methods which used in the measurements were a driving point and a direct method and these are presented in standard ISO-10846 in detail [6, 7]. In direct method measurement force is measured from the force output side (F2) of the part (see Figures 1 and 2) and the displacement is measured from the force input side (U1). In driving point method force is measured from the force input side (F1).

ANALYSIS METHOD

The analysis methods used for the determination of the dynamic transfer stiffness and the loss factor are presented in the standard ISO-10846 [6].

Dynamic stiffness can be defined from the equations:

$$k \approx \frac{F_2}{u_1} \text{ (direct method)} \quad k \approx \frac{F_1}{u_1} \text{ (driving point method)} \qquad (1)$$

Dynamic stiffness is a complex quantity from which the loss factor can be defined:

$$\eta \approx \frac{\mathrm{Im}[k_{2,1}]}{\mathrm{Re}[k_{2,1}]} \text{ (direct method)} \quad \eta \approx \frac{\mathrm{Im}[k_{1,1}]}{\mathrm{Re}[k_{1,1}]} \text{ (driving point method)} \qquad (2)$$

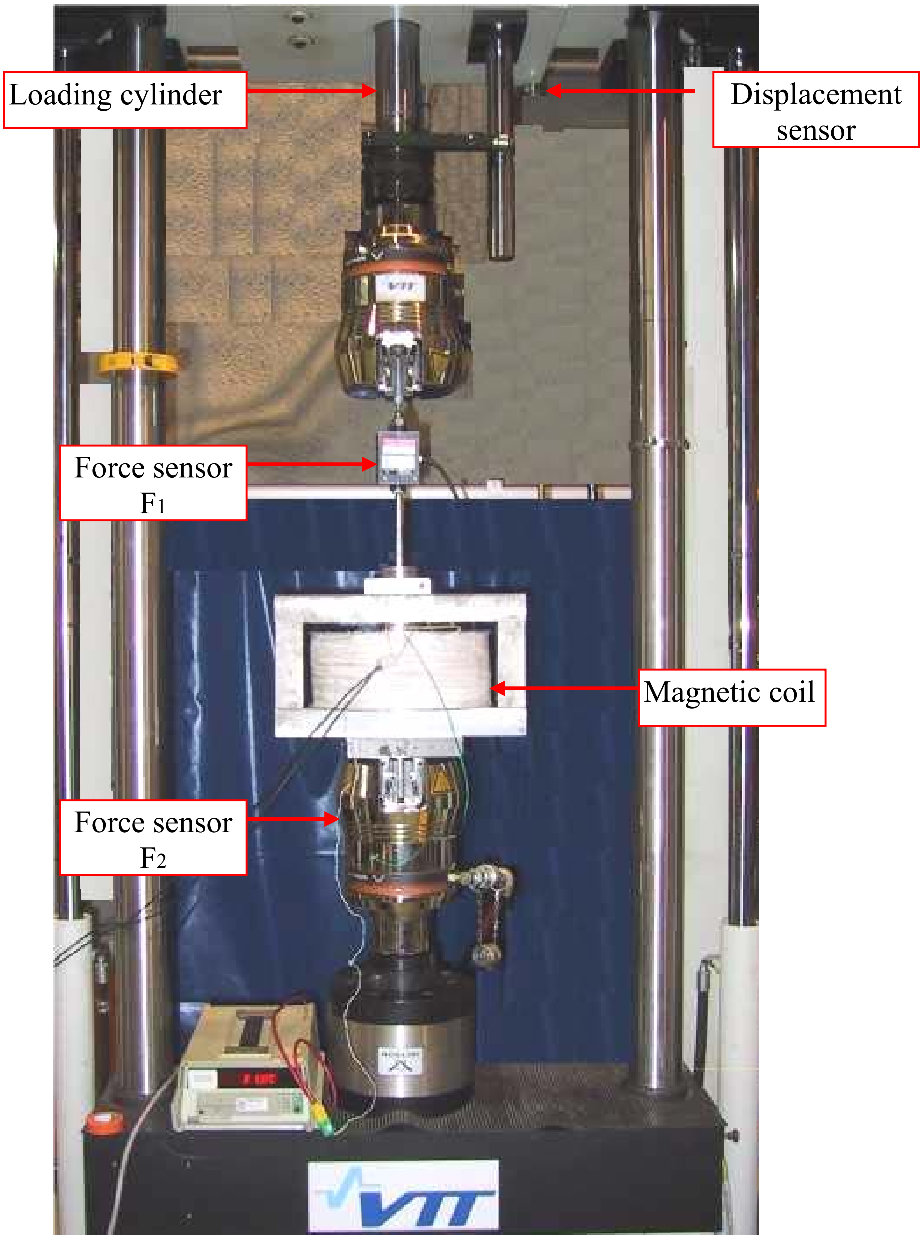

Figure 1. Test equipment.

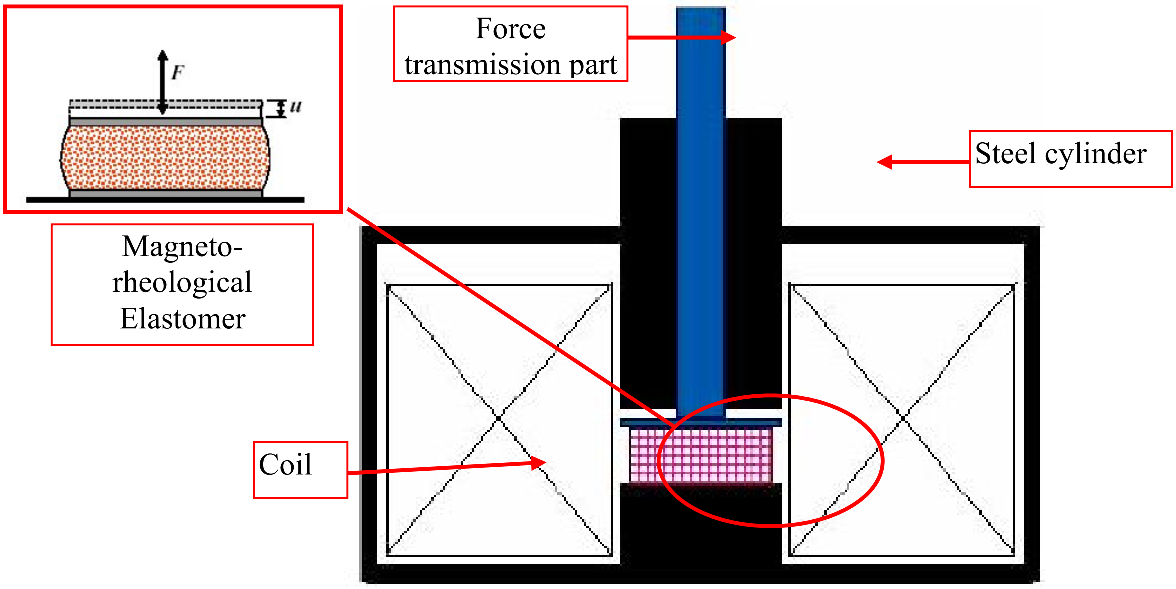

Figure 2. The schematic picture of the magnetic coil device with the MR elastomer.

CONDUCTED TESTS

First static tests were made for the three different compositions of MR-elastomers. This included measurements with varying magnetic flux density. The magnetic flux density was not directly measured during the test. However the relation between the coil current and the magnetic flux density is given in Figure 3. The curve in the Figure 3 is based on the magnetic flux density measurement, where the air gap between the steel cylinder and the coil frame structure was 25 mm (no force transmission part included). In the test situation the actual magnetic flux density is somewhat different due to the effect of magnetic permeability of the test specimen and that of the air gap between the force transmission part and the steel cylinder. In actual dynamic test the air gap of 25 mm was replaced with a MR test specimen, a 4 mm thick stainless steel plate (part of force transmission) and there was also about 2 mm thick air gap. In earlier studies it was shown that the measured permeability of the sample containing 30 vol-% of aligned iron particles is 3.34 [4]. This means that the actual magnetic flux density is higher in the test state especially at low coil currents. According to rough calculations, the coil current of 1.5A is enough to produce a magnetic flux density of about 1 T acting on the MRE sample, which is shown to be enough to saturate the sample containing 30 vol-% of aligned iron particles [5].

The dynamic tests were made with different displacements, pre-loads, amplitudes and with a varying magnetic flux density. Three displacement pre-loads were used: 0, 0.3 and 0.6 mm. In addition three displacement excitation amplitudes of ±0.125, ±0.25 and 0.5 mm were used depending on pre-load. Coil current was varied from 0 to 4.3 A. Tests were made with a constant sinusoidal frequency from 1 to 20 Hz (1, 5, 10 and 20 Hz). Tests were analyzed in frequency and time domain.

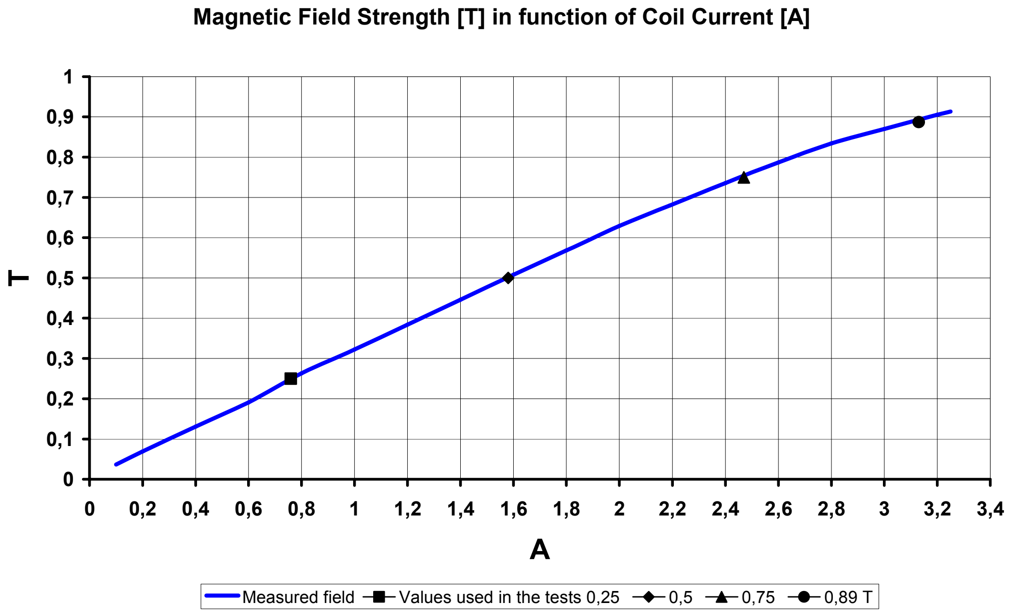

Figure 3. Magnetic flux density [T] in function of a coil current [A].

LABORATORY TEST RESULTS

Static measurements for material no 1 and 3 are presented in Figure 4. One can see that magnetic flux density has a clear effect on the displacement-force graphs. The slopes of the curves change when the displacement increases. Dynamic stiffness is presented in Figures 5 and 6 with various of magnetic flux density levels.

DISCUSSION

In the static tests stiffness increased approximately 100 % with the elastomer no. 1 when coil current was increased from 0 to 4.3 A when testing with displacement of 1 mm. Static stiffness increased approximately 200 % with the elastomer no. 3. The slope of the curves changes more with the elastomer no. 3 when the displacement increases.

Dynamic stiffness increased approximately 5 - 10 % when the frequency was increased from 1 to 20 Hz. The result was the same for all applied magnetic flux densities. Loss factor did not change significantly while the frequency was increased.

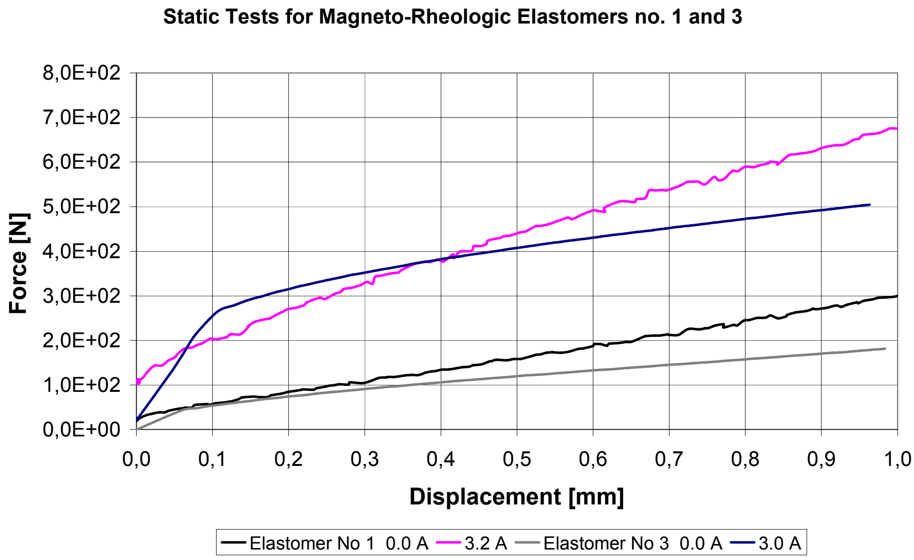

Figure 4. Static measurements to MR-elastomer (VTT material no. 1 and 3). The magnetic flux density is varied.

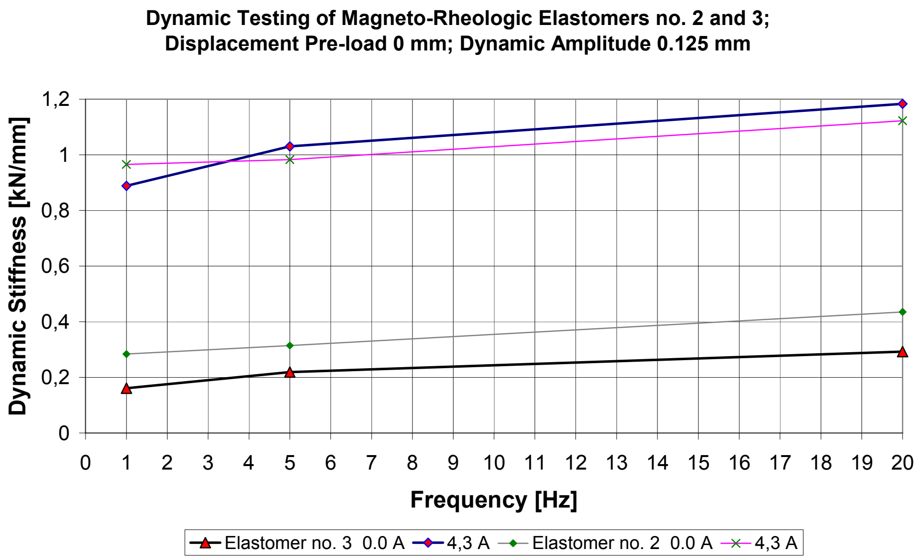

Figure 5. Dynamic measurements to MR-elastomer (VTT material no. 2 and 3) in tension-compression loading. The magnetic flux density is varied with dynamic amplitude of 0.125 mm.

Larger dynamic stiffness at higher frequencies is a typical phenomenon also in normal passive elastomer specimens without any particle fillings. This common phenomenon is due to the viscoelastic behavior of elastomers. The dynamic stiffness increased with all elastomers when magnetic flux density was increased. Elastomer no. 3 experienced the biggest changes in dynamic stiffness in tension-compression loading. When coil current was increased from 0 to 4.3 A the dynamic stiffness increased approximately 450 % with testing amplitude of ±0.125 mm and frequency of 1 Hz. Dynamic stiffness increased most while dynamic amplitude and pre-load were smallest.

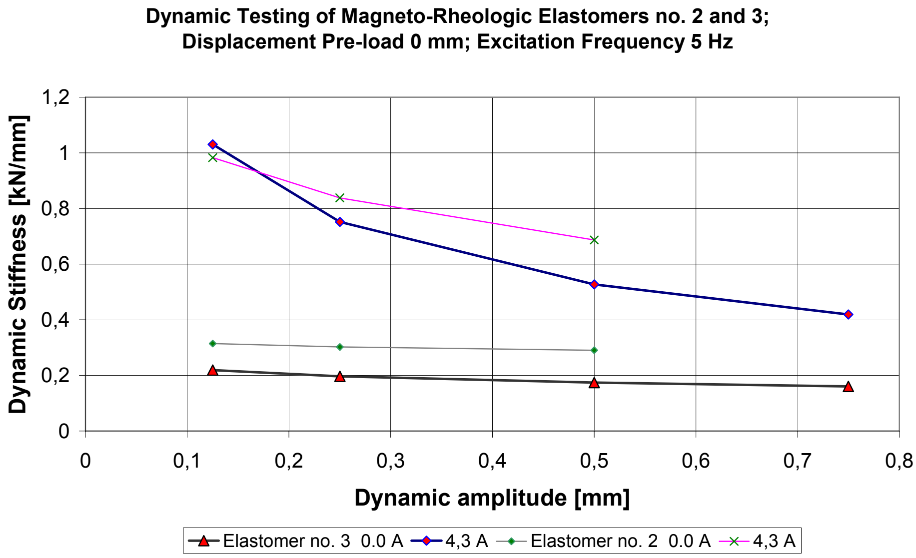

Figure 6. Dynamic measurements to MR-elastomer (VTT material no. 2 and 3) in tension-compression loading. The magnetic flux density is varied.

The decrease in dynamic stiffness as a function of the displacement amplitude (static and dynamic) is expected to be due to the deformation of the particle chains inside the MR-elastomer. The assumption is that after a certain deformation rate the magnetic interaction forces between the particles are influenced so that the stiffening property of the material in magnetic field vanishes. Static and dynamic stiffness does not increase significantly after 0,5 T magnetic flux density due to magnetic saturation of MR elastomers.

CONCLUSION

Dynamic stiffness increased approximately 240 % with the elastomer no. 2 while the magnetic flux density was increased. With elastomer no. 3 the change in dynamic stiffness was 450 % (tension-compression loading, excitation amplitude of 0.125 mm and frequency of 1 Hz). This shows that the optimal composition of magnetorheological elastomer is an important factor (tested elastomers had the same amount of iron particles: aligned and 30 % of volume).

Static stiffness increased approximately 100 % with elastomer no. 2 while magnetic flux density was increased. In dynamic testing the maximum measured increase was 240 %, which occurred while using tension-compression loading and small dynamic loading amplitude. The results indicate that, in order to achieve the largest possible stiffening effect, MR-elastomers should be used so that the total displacement amplitude would remain at sufficiently low level to preserve the particle interaction within a range where the stiffening effect of the material is possible.

Magnetic saturation of the MR elastomers begins after 0,5 T magnetic flux density, which indicates that 1 Tesla of magnetic flux density seems to be enough for this kind of elastomer. The usage of large electromagnets for producing the required magnetic flux density leads to relatively large heavy weight coil structure, which is quite impractical particularly when a robust coil is used to control a small-sized elastomer element. Redesigning the size and shape of the elastomer and the coil assembly could, to at least some extent, help in achieving more compact design for the element. An interesting possibility would be to apply strong permanent magnets together with some kind of distance control arrangement to adjust the magnetic field through the elastomer.

The use of magnetorheological elastomer as a semi-active stiffness control element in vibration control applications seems to be possible. The test results show that the dynamic stiffness and loss factor can be changed with the variation of the magnetic flux density. The achieved magnitude of stiffness change (100 – 450 % of the original value) is adequate for application where a relatively small stiffness change is enough to produce large enough change in dynamic properties of controlled structure. This is the case e.g. in application, where sharp slightly damped structural resonances are controlled.

Altogether, the research work done to develop magnetorheological elastomer material and required production technology shows promising results in the application of stiffness controlled elastomer spring/damper elements. Further research and development is needed to increase the dynamic stiffening effect and to design practical and compact element assembly including magnetic setup and energy efficient control procedure. Moreover, dynamic properties of MR-elastomers in audio frequency range should be studied in order to find out application potentiality in controlling for example structural vibration induced noise problems.

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