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Radiation resistance of 3D viscoelastic fluid dampers applied for the reduction of operational vibrations and seismic upgrading of piping systems in NPPs

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ABSTRACT

This paper describes the effects of ionizing radiation on the dynamic behavior of viscous fluid dampers by comparing stiffness and damping values before and after irradiation. Three different types damping fluids have been investigated.

INTRODUCTION

GERB Vibration Control Systems in Berlin and CKTI-Vibroseism in St. Petersburg have long lasting experience with viscoelastic fluid dampers in the fields of vibration control of heavy industrial machinery and seismic protection of equipment and large structures. Dampers for the protection of piping systems in conventional and nuclear power plants have been developed and are used worldwide. These dampers act as dynamic restraints and reduce the effects of operational vibrations as well as vibrations due to disturbances or seismic excitations.

These dampers work with different highly viscous fluids depending on the specific requirements of each application. In case of nuclear applications, the question of irradiation resistance is very important. GERB and CKTI have agreed on the testing of viscoelastic dampers by exposing them to different irradiation levels (γ-ray, Co-60) and measuring the impact on stiffness and damping characteristics. These tests have been performed with a standard damper design for piping applications.

VISCODAMPER - GENERAL DESIGN AND APPLICATIONS

Viscodampers are viscoelastic fluid dampers used to limit the motions of elastically supported systems in case of resonances or when subjected to shock-type, transient or random excitation. They add damping to a dynamic system and reduce occurring vibrations by dissipating mechanical energy.

In principle a viscoelastic fluid damper consists of three main components: damper housing, damper piston and damping fluid, see figure 1. The damper housing is filled with a highly viscous fluid and the damper piston is immersed in the damping fluid and can move in all directions, its motion only limited by the damper housing. Therefore, these dampers react and dampen motions in all directions. The damping force results from shearing and displacing the damping fluid. The force is approximately proportional to the relative velocity between damper piston and damper housing. Thus, viscoelastic fluid dampers do not support any static loads.

The actual damper response to dynamic loads consists of elastic and viscous components due to the viscoelastic behavior of the fluid and the elasticity of the steel parts. Thus, a damper is not only adding damping to a structure but also additional dynamic stiffness.

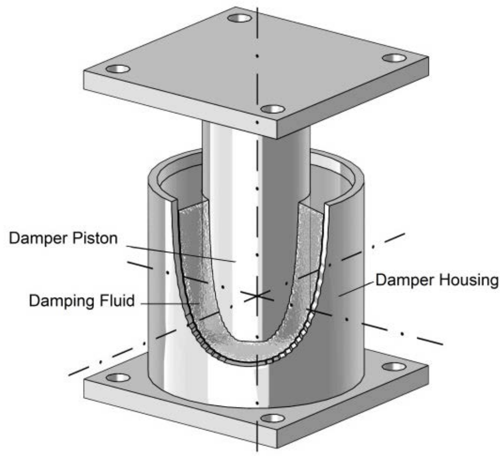

Figure 1: Principle Design of Viscodamper®

Viscodampers are used for:

- Vibration isolation of machinery and equipment
- Seismic protection of machinery and structures
- Damping and seismic protection of piping systems
- Damping of TMDs

VISCOELASTIC BEHAVIOR

Viscoelastic fluid dampers show distinct frequency dependent viscoelastic behaviour that can be described by means of the complex stiffness that combines elastic and viscous components in one quantity. The complex stiffness $\underline{K}$ is the quotient of the force and displacement amplitudes, see Equation 1 below:

$$\underline{K} = \frac{\hat{F}}{\underline{\hat{s}}} = K_{el} + j \cdot K_{vis} = K \cdot (\cos\delta + j\sin\delta) \quad (1)$$

The real part K_{el} is the elastic stiffness and is a measure for the elastic deformation resistant. The imaginary part K_{vis} is the damping stiffness and is a measure for the damping ability of the viscous elastic element, as shown in Equation 2:

$$K_{el} = K \cdot \cos\delta \quad and \quad K_{vis} = K \cdot \sin\delta \quad (2)$$

The absolute amount K of the complex stiffness is also called equivalent stiffness K_{eq}. The damping resistance d can be derived from the damping stiffness K_{vis} as shown in Equation 3

$$d = \frac{K_{vis}}{\omega} = \frac{\hat{F}}{\hat{s} \cdot 2\pi \cdot f} \cdot \sin\delta = \frac{\hat{F}}{\hat{v}} \cdot \sin\delta \qquad (3)$$

The dynamic characteristics are determined by force-displacement tests. These can be harmonic or random type motion tests. To describe the viscoelastic behaviour over a larger frequency range, measurements at several frequencies are taken by random noise excitation.

VISCOUS DAMPING FLUIDS

Today several different highly viscous fluids are used in dampers to provide specific damper characteristics and to meet application requirements. In this study the following damping fluids have been investigated:

- Bituminous damping fluids with high temperature dependency (VM20/0.6)
- Polybutene based damping fluids with medium temperature dependency (VM20-MTA/5)
- Silicone oil-based damping fluids with low temperature dependency (VM20/114)

These fluids have different base viscosities and temperature dependencies.

TEST PROGRAMS

Prior to the actual radiation exposure, the stiffness and damping behavior of all test dampers were determined in vertical and horizontal directions. All dampers are identical in design and dimensions, only dampers type VRD-10-40.x had 50% thicker walls.

During the irradiation test program, the dampers were exposed to 4 irradiation levels. Table 1 shows the scheduled and achieved levels. The relative error of the radiation exposure measurement of the test facility is +/- 12% with a confidence of 95%.

Table 1: Irradiation dosage

Damper Designation	Damping Fluid	Irradiation Power [kGy/h]	Duration [h]	Radiation Dosage [kGy]	
				scheduled	final
VRD-10-10.3	VM20/114 (silicone)	0,79	63	50	49,8
VRD-10-10.1	VM20/114 (silicone)	0,8	125	100	100
VRD-10-10.4	VM20/114 (silicone)	0,8	188	150	150,4
VRD-10-10.2	VM20/114 (silicone)	0,8	250	200	200
VRD-10-20.2	VM20-MTA/5 (polybutene)	0,79	63	50	49,8
VRD-10-20.1	VM20-MTA/5 (polybutene)	0,8	125	100	100
VRD-10-20.4	VM20-MTA/5 (polybutene)	0,8	188	150	150,4
VRD-10-20.3	VM20-MTA/5 (polybutene)	0,8	250	200	200
VRD-10-30.3	VM20/0.6 (bitumen)	0,79	63	50	49,8
VRD-10-30.4	VM20/0.6 (bitumen)	0,8	125	100	100
VRD-10-30.2	VM20/0.6 (bitumen)	0,8	188	150	150,4
VRD-10-30.1	VM20/0.6 (bitumen)	0,8	250	200	200
VRD-10-40.3	VM20/114 (silicone)	0,79	63	50	49,8
VRD-10-40.1	VM20/114 (silicone)	0,8	125	100	100
VRD-10-40.4	VM20/114 (silicone)	0,8	188	150	150,4
VRD-10-40.2	VM20/114 (silicone)	0,8	250	200	200

The properties of the fluids were checked visually and by tactile comparison (“screwdriver pinch test”). The color of the fluids had not changed, however with increasing irradiation level the silicone oil-based fluid got jelly-like as shown in table 2.

Table 2 Status of damping fluid

Damper Designation	Radiation dose [kGy]	Status of viscous fluid
VRD-10-10.3	50,0	Viscosity increased
VRD-10-10.1	100,0	Viscosity significantly increased
VRD-10-10.4	150,0	Gel
VRD-10-10.2	200,0	Gel
VRD-10-20.2	50,0	Viscosity unchanged
VRD-10-20.1	100,0	Viscosity unchanged
VRD-10-20.4	150,0	Viscosity decreased slightly
VRD-10-20.3	200,0	Viscosity decreased slightly
VRD-10-30.3	50,0	Viscosity unchanged
VRD-10-30.4	100,0	Viscosity unchanged
VRD-10-30.2	150,0	Viscosity unchanged
VRD-10-30.1	200,0	Viscosity unchanged
VRD-10-40.3	50,0	Viscosity increased
VRD-10-40.1	100,0	Viscosity significantly increased
VRD-10-40.4	150,0	Gel
VRD-10-40.2	200,0	Gel

DYNAMIC TEST RESULTS

Dynamic Tests before Irradiation

For comparison the following diagrams show the equivalent stiffness and the damping resistance of all dampers in vertical directions. The tests were performed at 20°C. The shown curves are averaged for each damper-damping fluid combination.

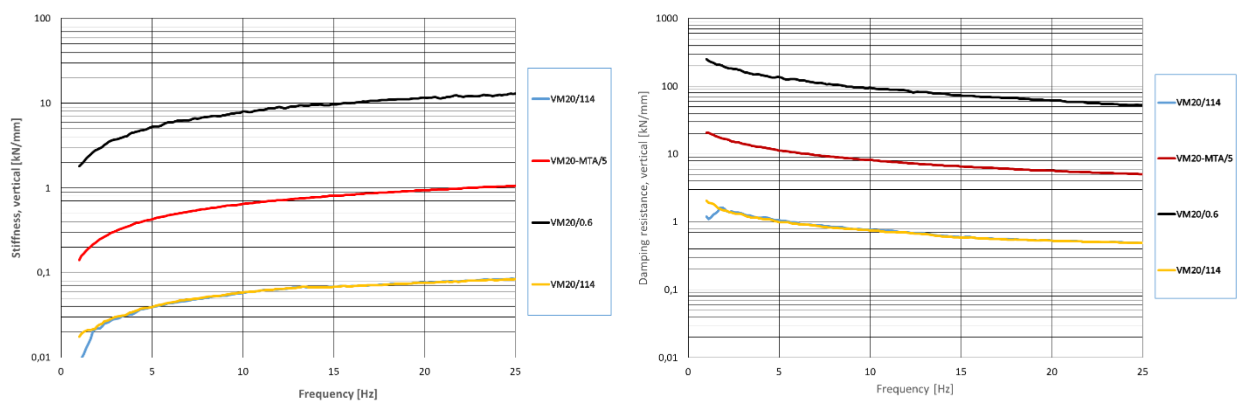

Figure 2: Equivalent stiffness and damping resistance before irradiation, vertical

Both curves show the impact of the different base viscosities of the fluids. In this test series the bituminous fluid has the highest viscosity followed by polybutene and silicone oil.

Dynamic Tests after Irradiation

The following diagrams show the measured vertical stiffness and damping curves of the different damper-fluid combinations for 50, 100, 150, and 200 kGy. For comparison the curves of a corresponding unirradiated damper is also shown.

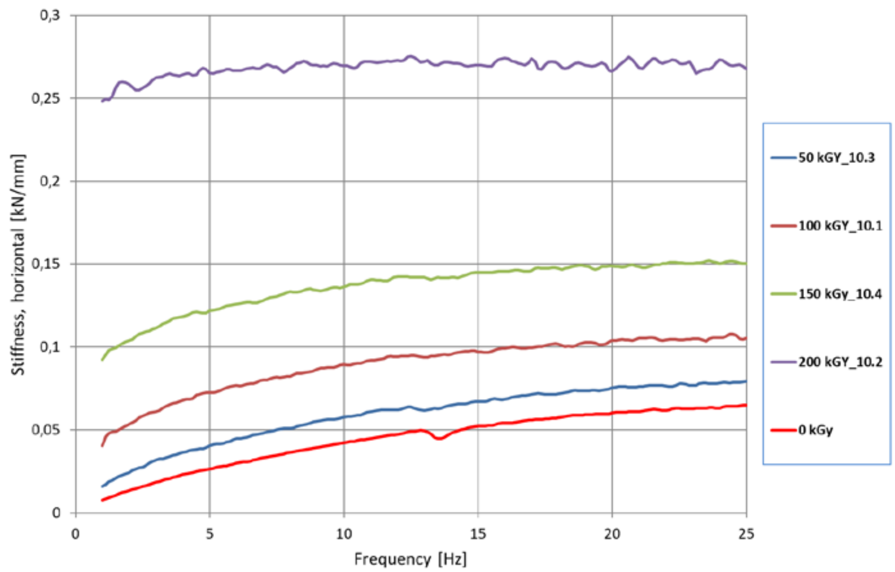

Figure 3: Comparison of horizontal stiffness VRD-10.10.1-4 (silicone)

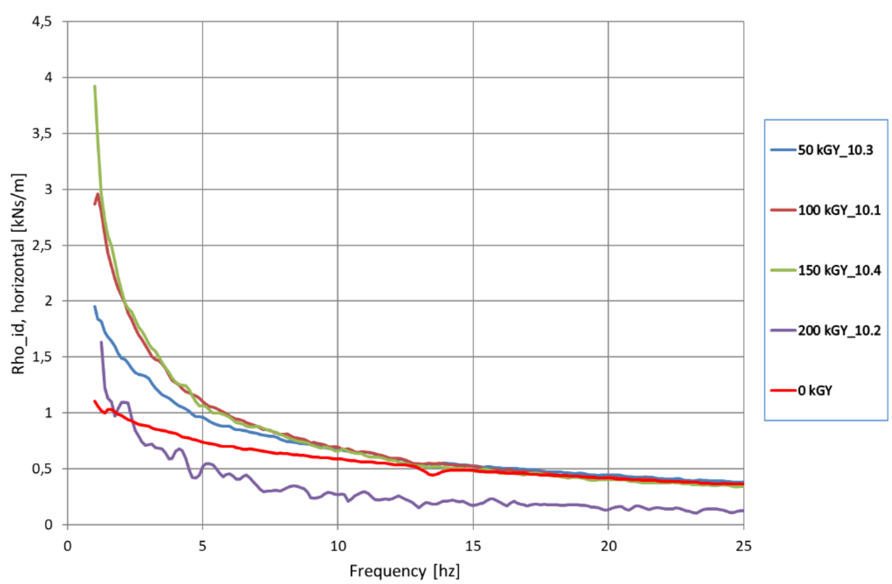

Figure 4: Comparison of horizontal damping resistance VRD-10.10.1-4 (silicone)

With increasing irradiation dosage, the reaction force and the equivalent stiffness of the dampers with silicone oil went up significantly. However, the damping resistance changes to a much smaller extend as the phase angle between force and displacement also gets smaller with increasing elasticity.

The silicone oil filled dampers type VRD-10-40.1-4 with 50% thicker walls show very similar results. With these high levels of irradiation, the increase of the wall thickness has no apparent effect on the radiation resistance.

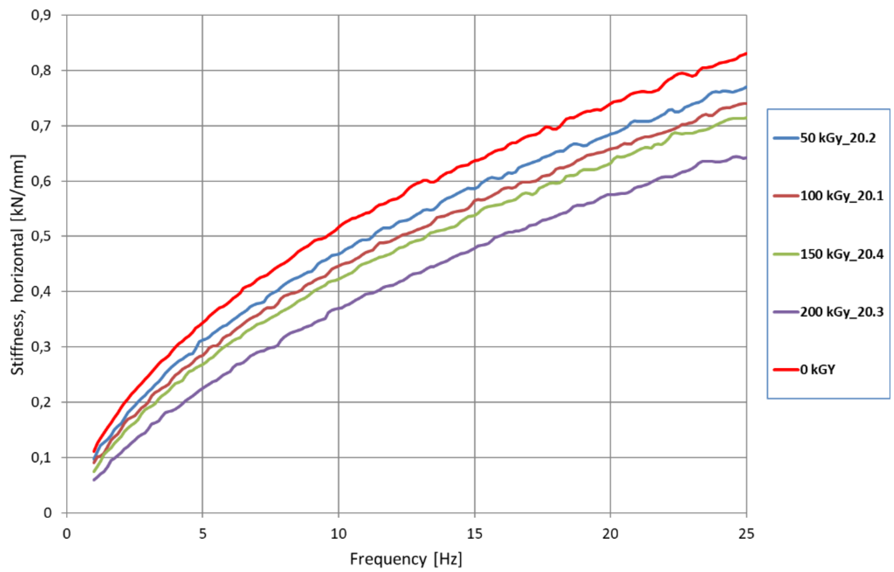

Figure 5: Comparison of horizontal stiffness VRD-10.20.1-4 (polybutene)

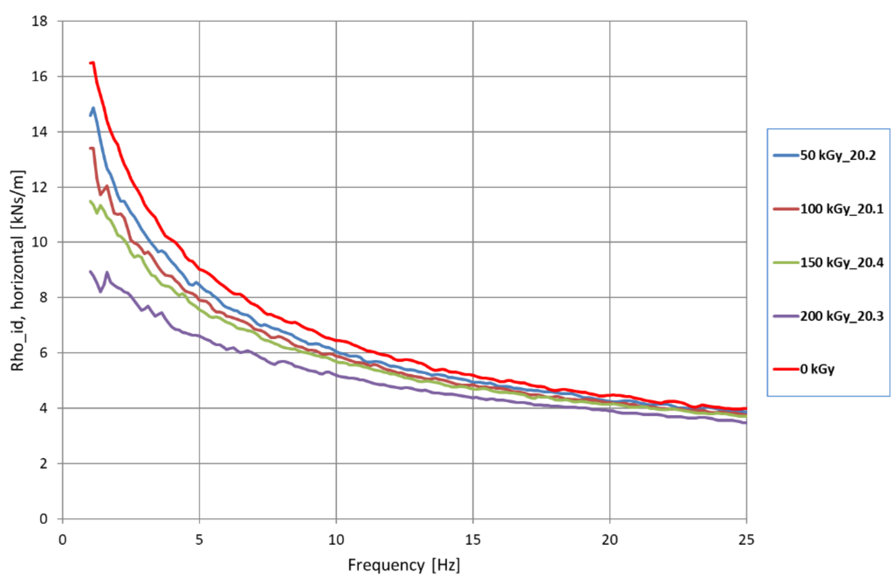

Figure 6: Comparison of horizontal damping resistance VRD-10.20.1-4 (polybutene)

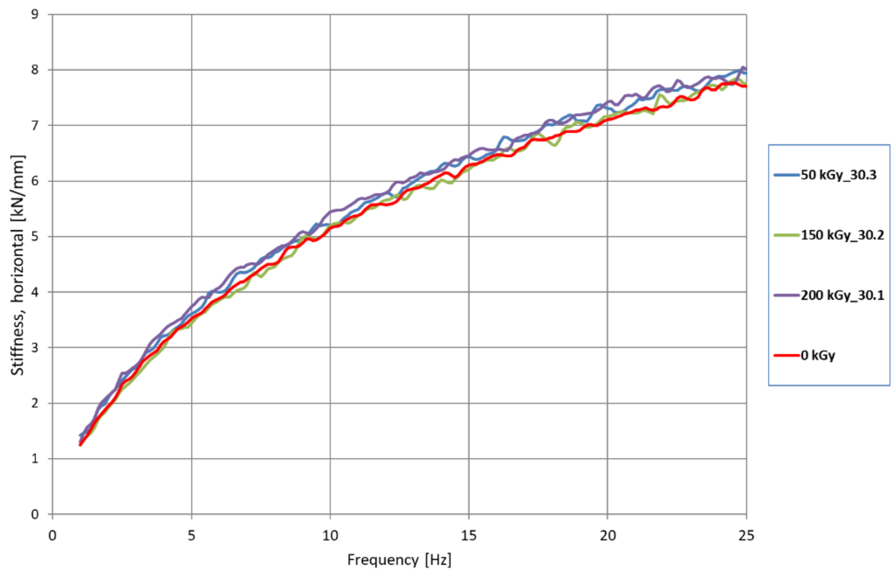

Figure 7: Comparison of horizontal stiffness VRD-10.30.1-3 (bitumen)

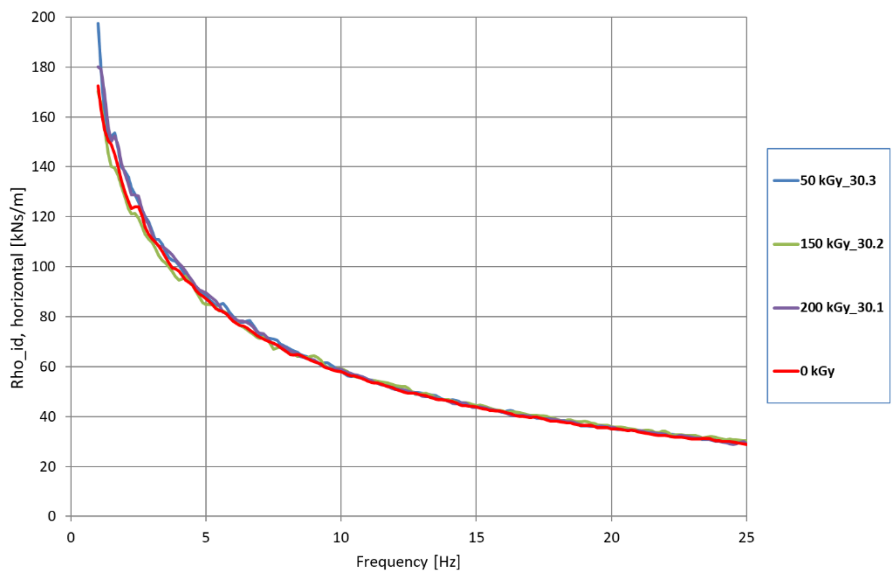

Figure 8: Comparison of horizontal damping resistance VRD-10.30.1-3 (bitumen)

The stiffness and damping curves show comparatively the resistance of the different damping fluid against ionizing radiation. Bitumen shows the highest resistance followed by polybutene and silicone oil. However, the small changes at lower irradiation levels allow for the use of silicone oils in radioactive environments for longer periods of time. Depending on the acceptable change of dynamic properties and the occurring irradiation a service life can be predicted and maintenance measures defined.

The following diagrams show resulting hysteresis loops of harmonic tests in vertical direction. The area is measure of the dissipated energy and damping. The inclination of the loop shows the elastic stiffness of the damper for the given frequency and amplitude. The viscosity of silicone oil increases with the absorbed radiation dosage. At some point the silicone fluid changes to gel and becomes more and more elastic losing its damping capabilities.

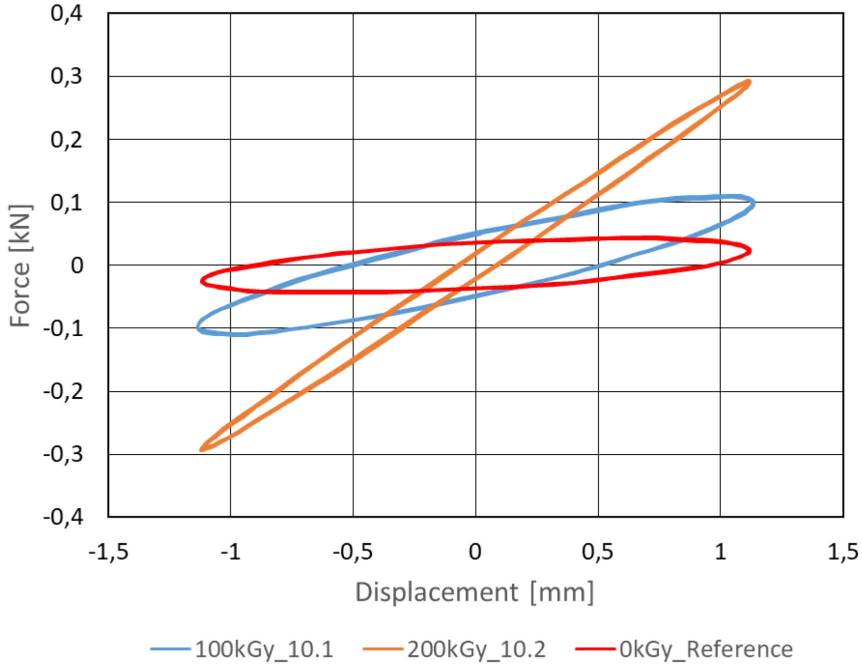

Figure 9: Vertical hysteresis loops, VRD-10.10 (silicone) (5 Hz, +/-1 mm)

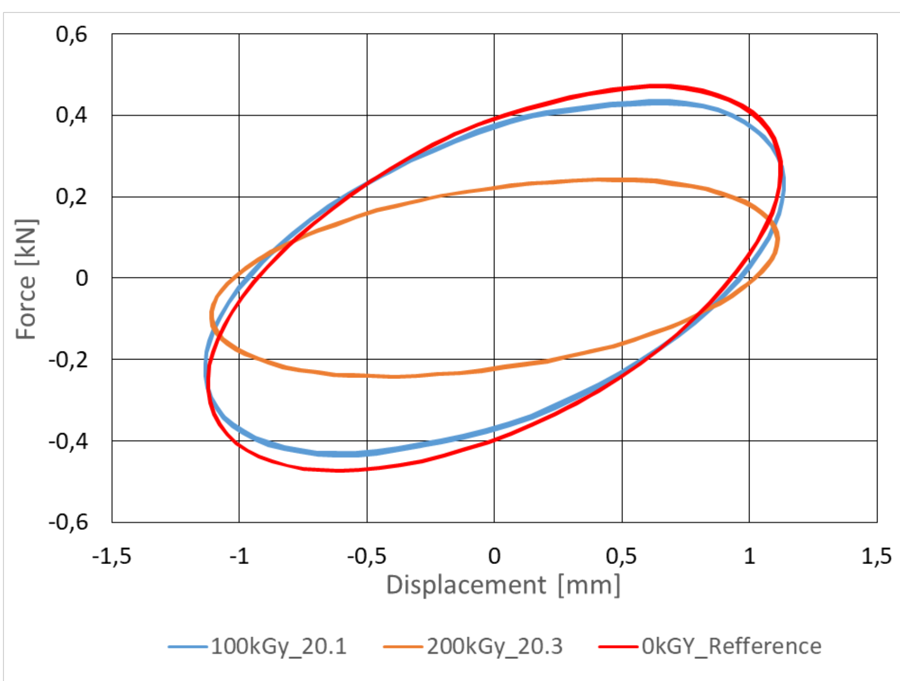

Figure 10: Vertical hysteresis loops, VRD-10.20 (polybutene) (5 Hz, +/-1 mm)

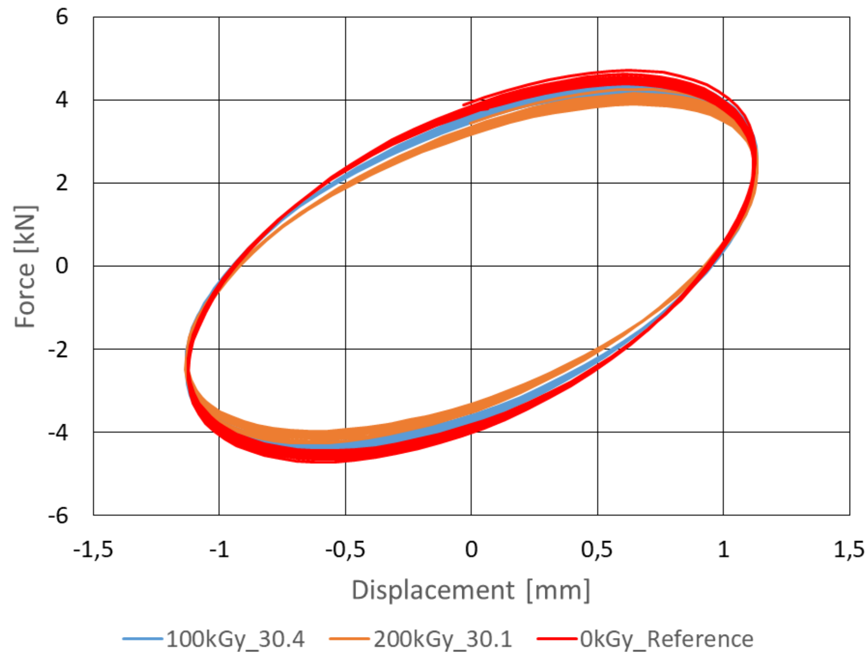

Figure 11: Vertical hysteresis loops, VRD-10.30 (bitumen) (5 Hz, +/-1 mm)

Bitumen didn't alter its viscosity despite the absorbed radiation dosage. Its molecule structure is very stable and radiation resistant. Stiffness and damping capabilities are not affected. This is one reason why bituminous dampers are often used in nuclear facilities with high radiation levels despite their high temperature dependent characteristics.

SLOW MOTION BEHAVIOR

In case viscoelastic fluid dampers are used for the protection of hot piping systems they might see slow thermal movement of the pipe when heating up and cooling down. In general, the resistance to these slow motions is very small due to the approximately velocity proportional behavior. Bitumen and polybutene don't change their resistance against thermal movement even after high irradiation dosage, whereas silicone oil shows an increasing resistance with higher irradiation levels. Table 3 shows force measurements of the different damping fluids for two velocities in vertical and horizontal direction. The resistances against slow motions of bitumen and polybutene is not affected by radiation whereas silicone oil shows an increasing resistance with higher irradiation levels especially when the fluid gels.

Table 3 Status of damping fluid

Damper	Irradiation level [kGy]	Fluid	Vertical Velocity		Horizontal Velocity	
			0.3 mm/s	0.033 mm/s	0.3 mm/s	0.033 mm/s
			max force [kN]		max force [kN]	
10.3	50	silicone	0,05	0,06	0,02	0,01
10.1	100	silicone	0,22	0,21	0,19	0,13
10.2	200	silicone	3,9	2,9	2,6	2,6
10.3	50	polybutene	0,04	0,04	0,02	0,01
20.1	100	polybutene	0,04	0,05	0,02	0,02
20.3	200	polybutene	0,05	0,05	0,04	0,04
30.3	50	bitumen	0,7	0,2	0,6	0,2
30.4	100	bitumen	---	0,2	0,7	0,2
30.1	200	bitumen	0,7	0,2	0,7	0,2
40.3	50	silicone	0,04	0,03	0,02	0,01
40.1	100	silicone	0,14	0,1	0,11	0,07
40.2	200	silicone	3,6	3,1	2,5	2,3

CONCLUSIONS

Random noise, harmonic and slow motion tests show all the impact of irradiation on the dynamic properties of viscoelastic fluid dampers.

- The bituminous fluid is most stable and hardly changes its characteristics within the tested irradiation range up to 200 kGy. This is true for all bituminous damping fluids used for pipework applications.
- The polybutene based fluid softens slightly when irradiated but stays fully functional within the tested irradiation range.
- The silicone oil-based damping fluid shows increasing stiffness and decreasing damping values with increasing irradiation levels. At high irradiation levels they gel and lose their liquid properties.

However, the tests prove that all three types of fluid can be used in areas of low and high irradiation. Depending on the occurring irradiation levels, inspection intervals for each fluid type can be defined. Exchange of fluid or replacement of devices can be scheduled in advance at those times.

REFERENCES

Walter Noll "Chemistry and Technology if Silicones", 1968.