Mechatronic Design of a Seismic Shaker

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Introduction

For seismic monitoring and exploration of oil and gas reserves it is needed to actively excite the ground, which is most often done with a shaker. The transmissibility of the ground is measured using a combination of sensors on the shaker and geophones on the ground. Especially in monitoring the reproducibility of the excitation signals must be high to detect any changes in the ground. Commercially available systems use hydraulics to create the required forces. For the excitation at low frequencies (2-5 Hz), the non-linear behavior of the hydraulics is the limiting factor in the performance of the shaker. In a first feasibility test with a linear motor in a horizontal shaker, good results were achieved but the design of that shaker was not suitable for seismic monitoring [1]. Therefore a new design had to be made for a seismic shaker which can achieve a high repeatability and controllability for seismic monitoring purposes. In this paper we describe the mechatronic design of this shaker, which is currently being built.

1 Working principle of a seismic shaker

A 1D dynamic model for a vertical seismic shaker is shown in Figure 1.

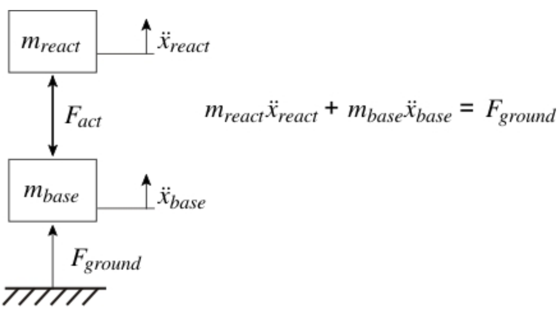

Figure 1: Dynamic model of a seismic shaker

A linear motor generates a force F_{act}, acting between the base-plate positioned on the ground and a reaction mass moving in opposite direction. The force inserted in the ground is equal to $m_{react}\ddot{x}_{react} + m_{base}\ddot{x}_{base}$, which is called the "weighted-sum ground force".

The proposed mechanical layout of the system is shown in Figure 2. Six ironless linear motors between base-plate and reaction mass generate a sinusoidal force of 6700N. To decrease the DC load on the actuators a low frequency spring suspends the reaction mass weight (gravity compensator). The guiding of the reaction mass is formed by six folded leafsprings, constraining the motions outside the vertical direction. The absence of friction guarantees low distortion of the measured ground force. Accelerometers on both base-plate and reaction mass are used to calculate the weighted-sum ground force. Main characteristics of the design are summarized in Table 1.

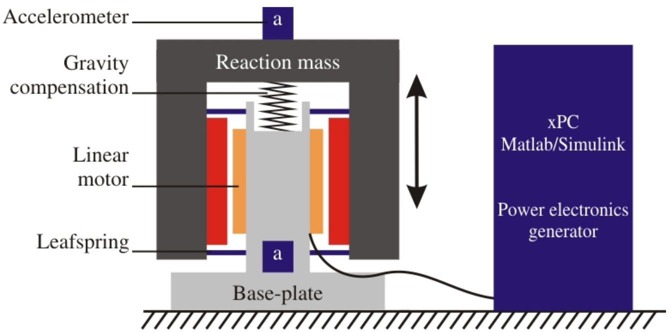

Figure 2: Proposed seismic shaker for seismic monitoring using linear motors. The gravity compensator of the reaction mass consists of a static air bellow. The guiding is realized with parallel leaf springs.

Reaction Mass	1000 kg
Base Mass	200 kg
Active force	6700 N
Frequency bandwidth	2-200 Hz
Active stroke	±42 mm

Table 1: Properties of seismic shaker design

2 Mechatronic design challenges

Simplified the ground can be seen as a spring, resulting in a resonance frequency of the base-plate on the ground. To get a reproducible and linear injection of the force at and above this resonance frequency, an active feedback loop is closed. The feedback loop is closed between the weighted-sum measurement signal and the actuator.

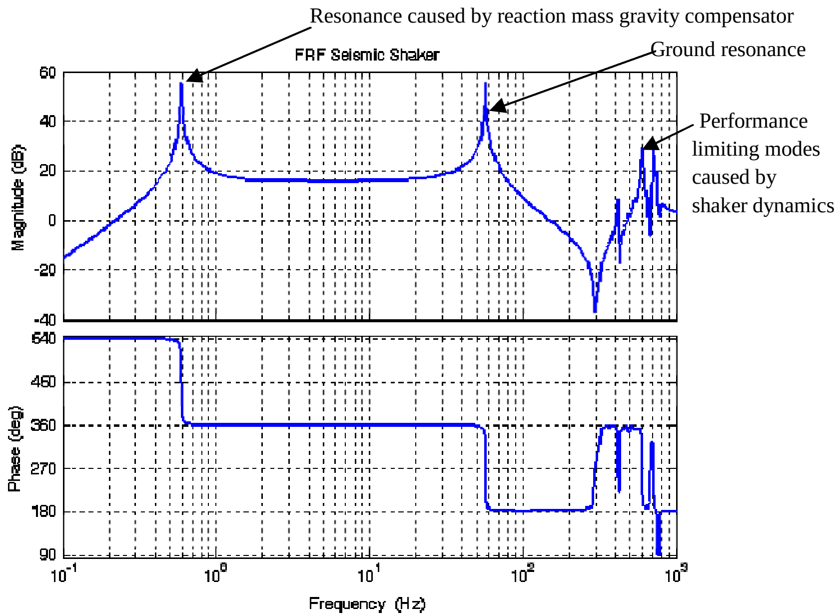

Figure 3: Typical FRF of seismic shaker: input actuator force, output ground force

One of the main challenges is obtaining a signal bandwidth of 2-200Hz without limitations from internal resonances within the 1000 kg structure. As can be seen in Figure 3 the stability of the feedback loop is limited by flexible modes of the shaker. Mechatronic optimizations were performed with regard to sensor and actuator placement (mode shape observability), reaction mass shape and plate spring design (damping).

3 Realization seismic shaker

Currently, all components of the shaker are tested separately and measurements are compared to simulation results. Figure 4 shows a picture of the assembled shaker. Clearly visible are the leafsprings to which special damping material is glued for damping the internal resonances of the leafsprings. First tests show that the leafspring guiding and the pneumatic gravity compensator work properly.

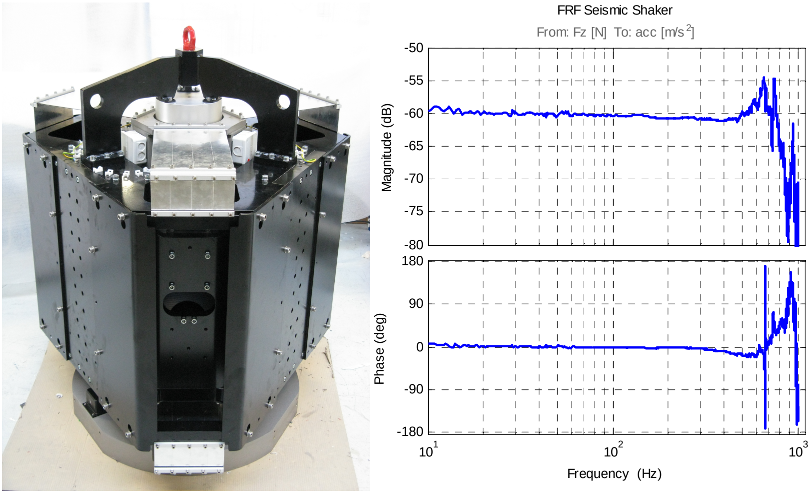

Figure 4: Assembled seismic shaker and FRF of the reaction mass

The suspension frequency of the reaction mass on the stiffness of gravity compensator plus leafsprings is measured at 1.2Hz (design specification 2Hz). First modal analyses on the reaction mass result in the FRF shown in Figure 4. The dominant resonances lie at 660Hz and 750Hz in line with the predicted behavior. Electrical connections are being finalized, so active control of the shaker was impossible at the time of writing.

4 Conclusion

A new seismic shaker has been designed and built. First measurement results show promising behavior, allowing for linear and reproduceable excitation within the specified frequency range of 2-200Hz.

References:

[1] A linear motor as seismic horizontal vibrator, G. Drijkoningen, A. Veltman, W. Hindrix, K. Faber, J. Brouwer , G.A. Hemstede, Extended Abstract no. Z99, Proceedings EAGE 2006, 12-15 June, Vienna, Austria.