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System structure identification and adaptive control of a seismic isolator test rig

Giandomenico Di Massa, Riccardo Russo, Salvatore Strano, Mario Terzo *

Dipartimento di Ingegneria Industriale, Università degli Studi di Napoli Federico II, Via Claudio 21, Naples 80125, Italy

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A B S T R A C T

This paper is focused on the modelling, the system identification and the adaptive control design of an unidirectional hydraulically actuated seismic isolator test rig.

The plant, constituted by the hydraulic actuation system and the isolator under test, is characterized by a non-linear behaviour and parametric uncertainties caused by the operating conditions and the unknown characteristics of the device to be tested. Therefore, a model reference adaptive approach is adopted for the position controller synthesis. To this end, a first order non-linear model is proposed and its structure identified.

Experimental results and simulations highlight the goodness of the proposed model and the effectiveness of the designed control for the hydraulically actuated isolator test rig.

1. Introduction

The seismic isolators are adopted in the base isolation strategies [1,2] in order to mitigate structural responses under strong external excitations, such as earthquakes and wind storms. The base isolation is typically effected by means of passive, semi-active or active systems [3,4] and all these are subjected to specific tests. Hydraulic actuation systems are employed to strain passive and semi-active isolators, with the intention of evaluating their characteristics in terms of restoring force and energy loss [5–7].

Hydraulic actuators are typically characterized by a significant non-linear behaviour [8] and a parametric uncertainty [9] due to the influence of the operating conditions on the parameter values. Consequently, traditional shaking-table testing was limited by the effectiveness of conventional fixed-gain linear algorithms used in their control. These algorithms are normally based on linear models of the shaking table, which parameters are assumed to be fixed for the duration of the test. As a consequence, the adaptive approach was adopted to meet this specific requirement [9–12].

In addition to the described features, the employment of a hydraulically actuated shaking table as isolator test rig involves an additional and more incisive source of model uncertainty caused by the presence of an isolator under test (IUT), whose constitutive law is fully unknown. Such devices are characterized by mechanical properties that can be very different for each pattern and depending, principally, on the structure that has to be isolated. So, the change of the IUT implies a modification in the system to be controlled and this has to be considered in the controller synthesis.

The employment of a hydraulic actuation to strain seismic isolators carries out towards a specific application that allows to consider a novel procedure in the modelling and control of the hydraulically actuated seismic isolator test rig. The approach

* Corresponding author. Tel.: +39 81 768 3285.
E-mail address: m.terzo@unina.it (M. Terzo).

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employed in the synthesis of the adaptive control of hydraulic actuators is commonly based [9,10,12,13] on the complete modelling of the system subjected to parameter variability. Because of the unknown nature (e.g. viscous, hysteretic, liner/non-linear) of the seismic isolator to be tested, the complete modelling of the system (hydraulic actuator+IUT) is not allowed in the described application: in fact, the semi-active and passive seismic isolators can strongly differ from each other for both static and dynamic properties. Consequently, the paper focuses on the identification of a versatile structure of the whole system highlighting that the hydraulic actuation system, combined with the IUT, is characterized by a behaviour that can be well approximated by a first order dynamics, independently from the characteristics of the IUT. While in a previous work of the authors [14] the plant to be controlled consisted of the hydraulic actuation system in presence of an external disturbance due to the IUT, in the present study the controller aims to adaptively make the whole system (hydraulic actuator and IUT) able to track a target displacement. So, the presented approach appears more functional if a substantial variability of the operating conditions and of the IUT characteristics mark the test.

As a first step, a fifth order non-linear model (5th OM) of the test rig is derived and its validation illustrated. The 5th OM fully describes the isolator test rig in terms of typical dynamics, soft and hard non-linearities and consequently is assumed as completely faithful to the plant. Successively, by means of a system structure identification technique, a simplified model, functional for the controller synthesis, is obtained. Indeed, starting from experimental data, the structure of a first order non-linear system, with parameters depending on both the operating conditions and the IUT, is identified. The theoretical-experimental comparisons confirm the soundness of the proposed first order non-linear model (1st OM) which can be assumed for the controller design. So, a model reference adaptive control is synthesized and tested by means of numerical simulations carried out on the validated 5th OM and in presence of different IUT. The numerical results confirm the effectiveness of the proposed algorithm and validate the illustrated approach.

The paper is organized as follows: the test rig and its mathematical model are described in Section 2. The 1st OM identification procedure and adaptive control design are described in Sections 3 and 4, respectively. Simulation results are discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. Test rig description and modelling

The test rig consists of the equipment described in [14–16], which is mainly constituted by an unidirectional hydraulically actuated sliding table. The isolator under test is placed between the sliding table and a vertical slide. Shear tests on the IUT are conducted assigning suitable displacement laws to the sliding table, in presence of a fixed vertical load obtained by means of a hydraulic jack.

In the following, the test rig mathematical model is derived. Primarily, the modelling refers to the testing machine in which no isolator is installed: the hydraulic actuator has to move the sliding table only. Successively, the IUT restoring force will be accounted for.

The modelling procedure is based on the following hypothesis: (a) fluid properties not depending on temperature; (b) equal piston areas; (c) equal chamber volume for each side in the case of barrel in the centred position; (d) negligible internal and external fluid leakages.

In particular, the actuator can be modelled as a double-ended hydraulic cylinder driven by a four-way spool valve (Fig. 1).

The pressure dynamics is given by:

$$\frac{V_0}{2\beta}\dot{P}_L = -A_p\dot{y} + Q_L \tag{1}$$

where $P_L = P_A - P_B$ is the load pressure, P_A and P_B are the pressures in the cylinder chambers, V_0 is the volume of each chamber for the centred position of the barrel, A_p is the piston area, $Q_L = (Q_A + Q_B)/2$ is the load flow, Q_A and Q_B are the flow rates to the chambers, β is the effective Bulk modulus and y is the table displacement.

The motion equation of the sliding table is:

$$m\ddot{y} + F_f = A_pP_L, \tag{2}$$

where m is the movable mass, F_f is the friction force due to the hydraulic actuator and linear guides.

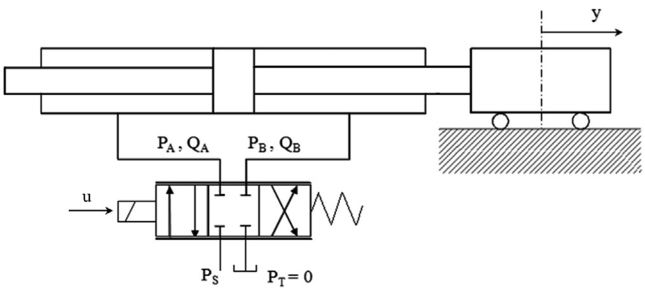

Fig.1. Scheme of the hydraulic actuator adopted for the mathematical model.