Data set for "Data-based Detection and Diagnosis of Faults in Linear Actuators"

1. Introduction

The dataset presented here was acquired for the study of degradation in linear actuators, particularly electro-mechanical actuators (EMA). The data was acquired from an instrumented rig (described in section 2) where a ball-screw actuator moved left to right following a defined motion profile with a level of load selected by the user. Nut position and motor current measurements were acquired during the tests.

Initially the rig was tested in normal conditions (absence of faults) under different motion and loading scenarios. Subsequently different mechanical faults, including lack of lubrication, spalling and backlash, were seeded in the system. Position and motor current data were acquired under these conditions to study monitoring methods to detect faults and degradation in this particular type of systems.

This document describes in detail the data files available in the repository. Section 2 shows the experimental set up. Section three describes the different cases studied and finally the data structure is explained in section 4.

2. Experimental set up

A ball-screw mechanism where threaded shaft provides a helical raceway for ball bearings housed inside a nut was selected for this study. This arrangement allows the transformation of shaft rotation into nut linear displacement with little friction and high precision. In order to simulate varying loading scenarios that represent realistic operating conditions, a second actuator was used. Both actuators were connected through a load cell, and the load measurements provided were fed back to the controller of the second actuator. Using this configuration it is possible to send a load set point command to the second actuator and take control of the external load in the actuator being tested.

Ball-screws with fitted anti backlash ball-nut model RM1605-C7 with 5 mm lead and Nema 34 stepper motors with 4.6 Nm holding torque were selected. The mechanical components were mounted on an aluminium profile structure. The motors of both actuators were controlled from a Labview interface, which was also responsible for the data collection.

The rig was instrumented with a series of sensors for control and monitoring purposes. Position was measured with a Vishay REC 115L linear potentiometer. Current from the drive is measured by a Honeywell CSLA2CD Hall effect sensor. The load between both actuators was measured using a Tedea Huntleigh, S beam type model 614 load cell. Load measurements were used only for controlling the load provided by the second actuator, but never for monitoring purposes. All the data was acquired at 25 Hz.

This rig design is capable of producing a displacement of 120 mm with a maximum external load of 40 kgf in both directions. The approximate dimensions of the complete rig are 75cm long, 35 cm wide and 25 cm high. Fig. 1 shows a CAD model of the test rig where some parts of the structure have been removed for more clarity. The nut of the actuator being tested is connected through a machined aluminium block to two linear bearings mounted on rails to avoid rotation of the nut. Pictures of the assembled test rig can be seen in Fig. 2.

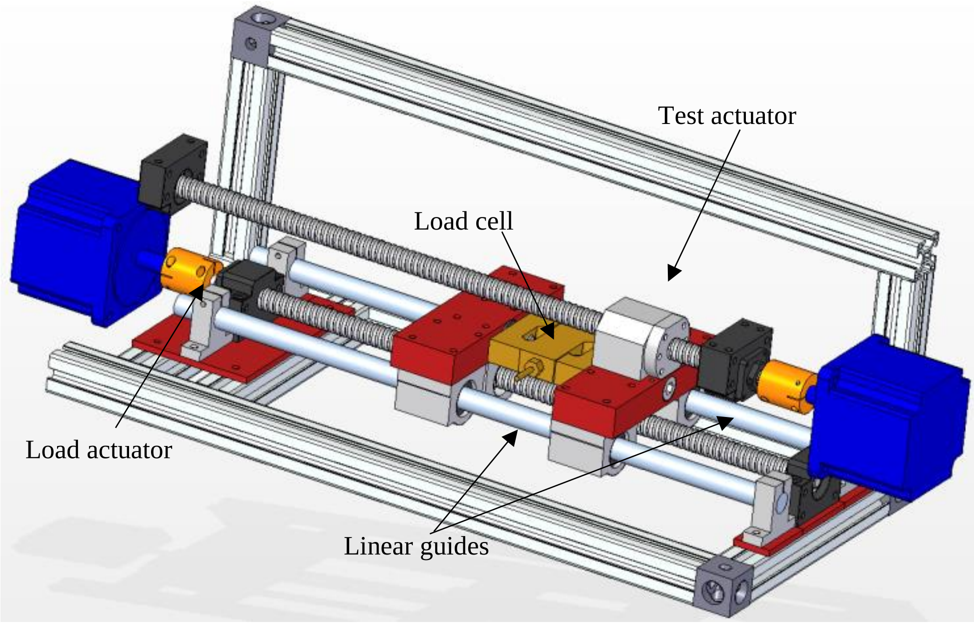


Fig. 1: 3D model of the test-rig

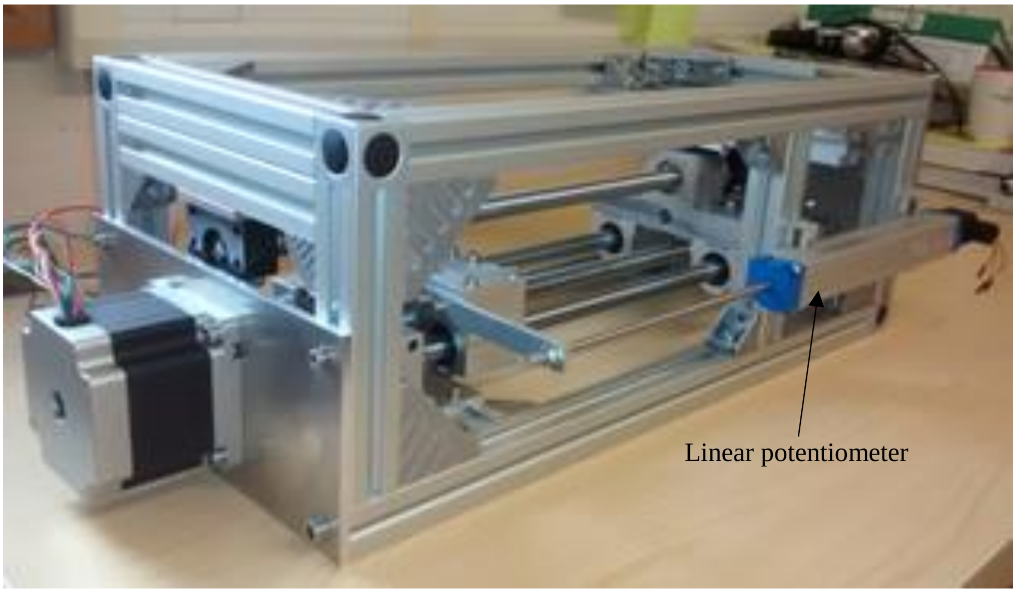


Fig. 2: Lateral view of the rig

3. Cases studied

Initially the rig was run under normal operating conditions (absence of faults) in order to collect a significant amount of data that can represent the behaviour of the system under different loading conditions and motion profiles. Two motion profiles were tested. The first was a trapezoidal motion profile (constant speed set point) where the

120 mm stroke was completed in 5 s with 3 s waiting at both ends of the movement. The second was a sinusoidal motion profile (smooth speed transition) with 120mm stroke completed in 6 s with 2s waiting at both ends. These two motion profiles were tested for normal and faulty conditions under three different loading scenarios: 20 kgf, 40 kgf and -40 kgf. The full motion sequence was repeated 5 times in each test, and each test was repeated 10 times in order to generate a dataset with a significant amount of observation in each case studied. In every test, before the data collection started, the rig was run for about 30 mins until a steady temperature was reached in the motors and the nut.

Additionally, three different mechanical faults were introduced in various parts of the system. Tests were run on the faulty system using the same motion profiles and loading conditions used under normal operation. The faults introduced were selected to be representative of critical failure modes of this type of machine. The faults tested were:

- lack of lubrication: simulated by removing gradually the screw lubricant and tightening the nut seals (Fig. 3);
- spalling: simulated by artificially inducing surface defects of different sizes in the screw and balls (Fig. 4)
- backlash: simulated by replacing the original balls with balls of smaller diameter (Fig. 5).

Seeded faults were introduced because there was insufficient test time to run the ball screws naturally to failure. The faults were introduced gradually in order to observe how the severity of the faults affect the measured signals.

In the case of lack of lubrication, in the first stage the lubricant was removed with degreaser. No dramatic changes were observed in the signals, mainly due to the inherent low friction of the ball-screw architecture. In order to increase the severity of the fault, the bolts holding the plastic seal at both ends of the nut containing the balls were tightened, to create more friction (see Fig. 3).

Fig. 3: Bolt holding seal in ballnut

The spalling defect was started as a 1 mm diameter surface defect on the rolling surface of the screw (see Fig. 4)). In the following 2nd, 3rd and 4th stages the size of the defect was gradually increased to 2, 3 and 4 mm in diameter, affecting not only the bottom of the channel but also one of the sides. In stage 5 the 4 mm defect was replicated in a neighbour channel, and in stage 6 the size of both defects was increased affecting the sidewall between them. In stage 7 another 4 mm defect was seeded on the other neighbour channel of the original defect. Finally in stage 8 part of the sidewall between two of the defects was partially removed (see (see Fig. 4)).

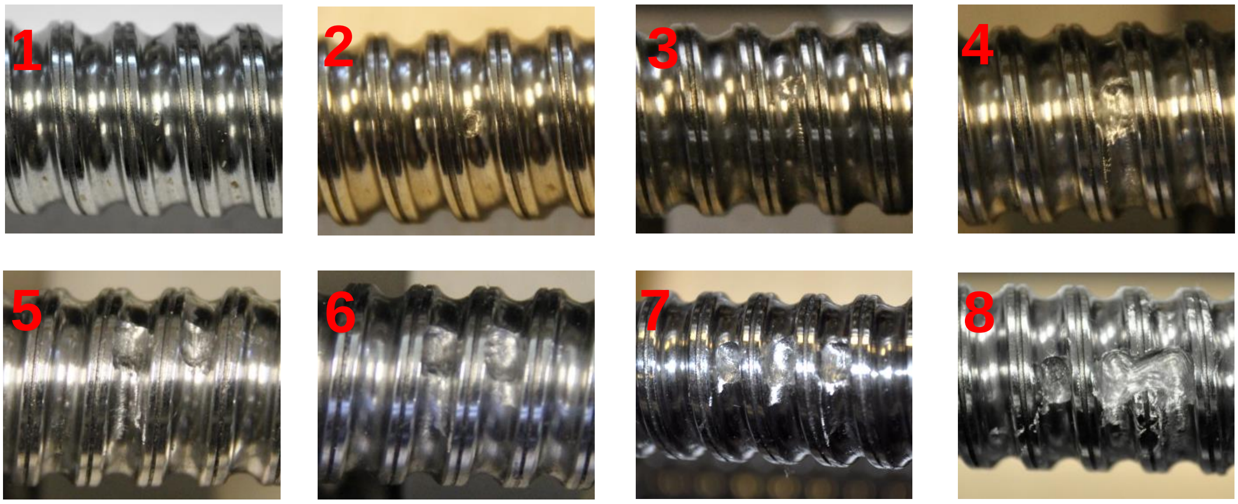
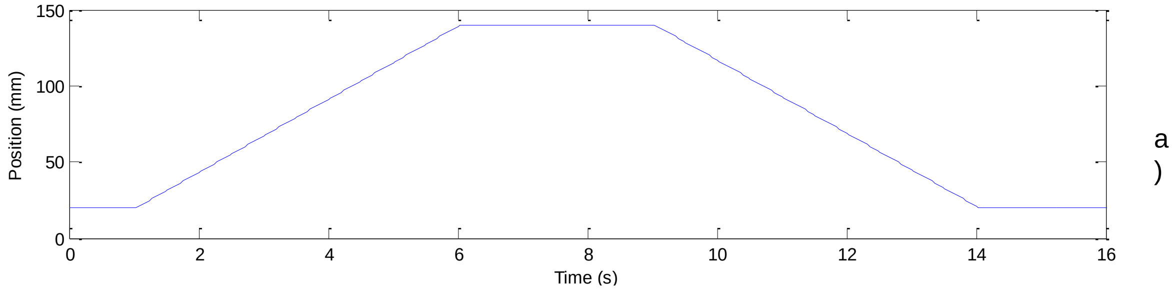


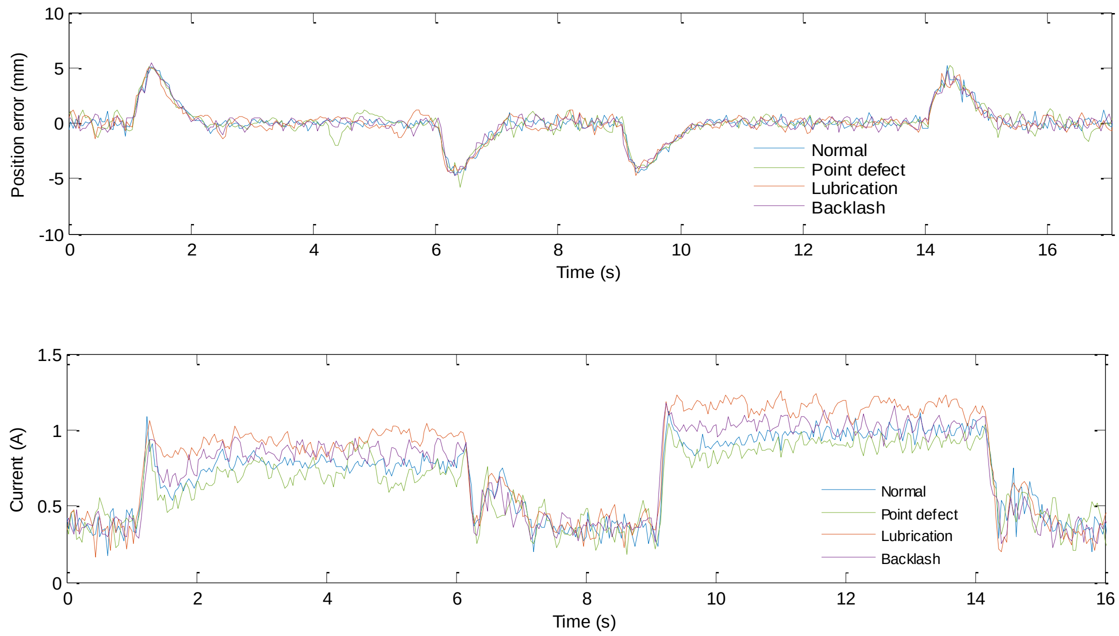
Fig. 4: 8 stages of the spalling defect

Backlash or excess of play was simulated replacing the original 3.15 mm diameter balls by 3 mm and 2.5 mm diameter balls (see Fig. 5).

Fig. 5: Balls for simulation of backlash

Fig. 6 shows an example of the data acquired under normal and faulty conditions for a trapezoidal motion profile. The top graph a) shows the position set point, b) shows the position error (difference between position set point and actual position measurement) and current measurements are shown in c).





b)

c)

Fig. 6: Example of data acquired, a) position set point, b) position error, c) current

4. Data structure

The data acquired was stored using the Matlab .mat file format. In this case study there are 13 .mat filed corresponding to normal operation and the different degradation stages of the faults tested:

Name	Type	Size
Backlash1.mat	MATLAB Data	1,875 KB
Backlash2.mat	MATLAB Data	1,904 KB
LackLubrication1.mat	MATLAB Data	1,905 KB
LackLubrication2.mat	MATLAB Data	1,905 KB
Normal.mat	MATLAB Data	1,904 KB
Spalling1.mat	MATLAB Data	1,906 KB
Spalling2.mat	MATLAB Data	1,907 KB
Spalling3.mat	MATLAB Data	1,907 KB
Spalling4.mat	MATLAB Data	1,907 KB
Spalling5.mat	MATLAB Data	1,905 KB
Spalling6.mat	MATLAB Data	1,904 KB
Spalling7.mat	MATLAB Data	1,904 KB
Spalling8.mat	MATLAB Data	1,907 KB

Fig. 7: List of files included

Normal. Mat corresponds to the data acquired under normal operation. Backlash1.mat and Backlash2.mat correspond to the first and second stages of backlash tested. Similarly LackLubrication1.mat and LackLubrication2.mat correspond to the first and second stages of lack of lubrication. The remaining 8 files named as SpallingX.mat refer to the corresponding stage of spalling tested.

Each file contains 60 matrices, corresponding all the possible combinations between the 2 motion profiles and 3 loading conditions repeated 10 times. The naming system of each matrix provides information about the motion profile, load and test repetition number:

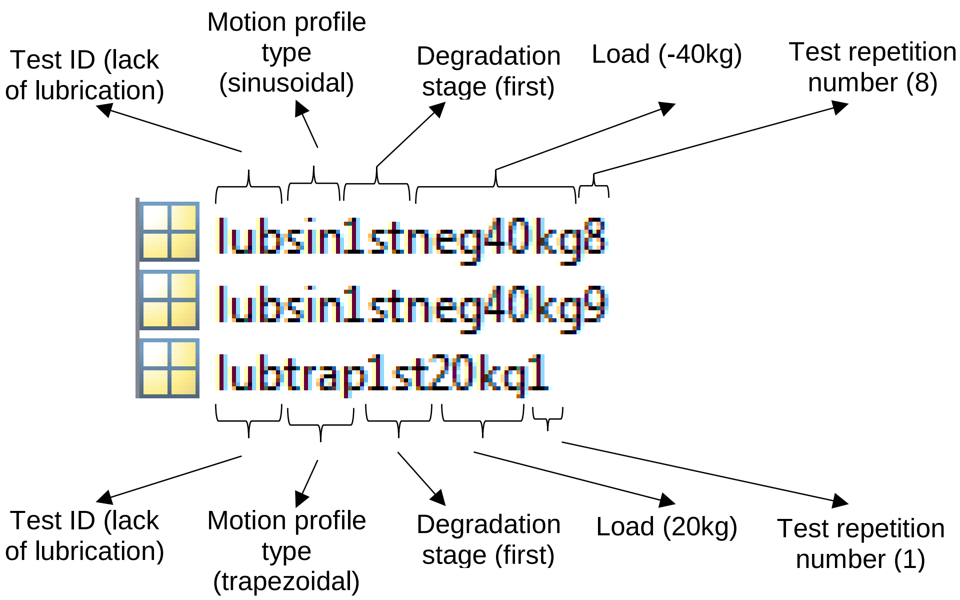


Fig. 8: Matrix naming

Finally each matrix contains 3 columns, corresponding to the measurements of position set point (for reference), the position error achieved by the controller and the current fed to the motor respectively. The rows correspond to the different observations of these three parameters acquired at 0.04 s intervals.