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PREPARATION OF THE VTT'S 1.1 MN HYDRAULIC AMPLIFICATION MACHINE FOR THE MODERNIZATION OF THE CONTROL SYSTEM

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Abstract: This paper describes the preparation methods off VTT's 1.1 MN force standard machine (FSM) before modernization of its control system. Working principle of the machine is introduced. A customized datalogger to investigate the FSM functionality and dynamic behavior is developed and described. The plan for the investigation of the 1 MN force standard machine's control system is also introduced.

Keywords: Preparation, force standard machine, modernization.

1. INTRODUCTION

The 1.1 MN force standard machine with hydraulic amplification was installed originally in a designated calibration laboratory of Lahti Precision Oy in Lahti in 1985. Afterwards, in 2011, the machine was reinstalled in Kajaani, when operations of the calibration laboratory were moved [1]. After over 30 years of operations, the original control system of the machine has come to the end of its life cycle. Logic control type used in the machine has no support from the manufacturer anymore. Because of the significance of the machine for the force laboratory of national metrology institute of Finland, the modernization of the machine has been decided. As a preparation for the modernization project and because of a lack of documentation for the control logic, machine's functionality and dynamic behavior is going to be under investigation.

2. 1.1 MN FORCE STANDARD MACHINE

The principle of hydraulic amplification is well known and it is presented in several articles [2], [3]. The working principle can be described like a pressure balance between two coupled hydraulic piston cylinders with different effective areas: A_1 for measurement cylinder and A_2 for working cylinder. In an ideal case, the force F_1, generated on the deadweight machine, is amplificated to the force F_2 on the working cylinder by the effective areas ratio of the piston cylinders:

$$F_2 = \frac{A_2}{A_1} \cdot F_1 \qquad (1)$$

In order to fulfil the equation 1, the oil pressure p_1 on the deadweight side must be equal to the pressure on the working side p_2 so that the same pressure p can be used on both sides of the pressure balance. Only under these conditions, the valid equation is:

$$\frac{F_1}{A_1} = p_1 = p = p_2 = \frac{F_2}{A_2} \qquad (2)$$

The schematic diagram of the VTT's 1.1 MN force standard machine is introduced in Fig. 1. The machine, made by German company Erichsen in 1985, is a combined model of dead weight machine and hydraulic amplification machine. The deadweight machine capacity is 20 kN - 110 kN with standard uncertainty of 0.005%. Force steps are generated by three different mass stacks 11 x 2 kN, 11 x 5 kN and 11 x 10 kN. For the higher capacity, the deadweight force, generated by the weights (18) on the measurement cylinder (15), is hydraulically amplificated by a factor of 10 up to 1.1 MN with standard uncertainty of 0.01%. To avoid the hysteresis-caused friction, the piston of the working cylinder (2) and the measurement cylinder on the deadweight side (15) are rotating.

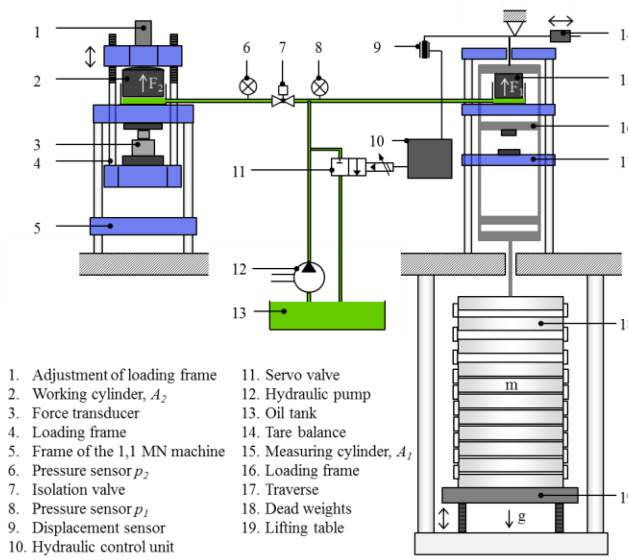

Fig. 1: Schematic diagram of VTT's 1.1 MN force standard machine

The hydraulic design and hydraulic control system of the 1.1 MN force standard machine is realized so that the pressure on the working side and on the deadweight side is equal. Firstly, the dimensions of the pressure line between working side and deadweight side are optimized for minimum pressure losses. Secondly, pressure sensors are used in the machine to achieve the equilibrium for the oil pressure between the working cylinder and the measurement cylinder.

3. TUNING OF THE MACHINE

The 1 MN machine tunes for operation in two phases. The weight of the force transducer, which is going to be calibrated on hydraulic amplification machine, is producing additional pressure increase on the working cylinder side, which is causing the difference in hydraulic oil pressures between working cylinder side and measuring cylinder side. This pressure difference has to be compensated by a tare balance on the measuring cylinder side (14 in Fig 1). To measure this pressure difference, the hydraulic control unit uses pressure sensors; p_2 on the working side and p_1 on the deadweight side (6, 8 in Fig. 1). Hydraulic connection of the pressure sensors on the pressure line enables the sensors to be isolated from the main pressure line as well as from each other.

When tuning the machine, the pressure sensors are coupled and preloaded three times sequentially on 120 second cycles; firstly to the oil tank pressure and then to preload pressure (Fig. 2). This preload pressure is generated by a working cylinder from the weight of the loading frame and the force transducer laying on it. When the tank pressure is coupled to the pressure sensors, the operator adjusts zero readings of the pressure sensors on the amplifier to the same level.

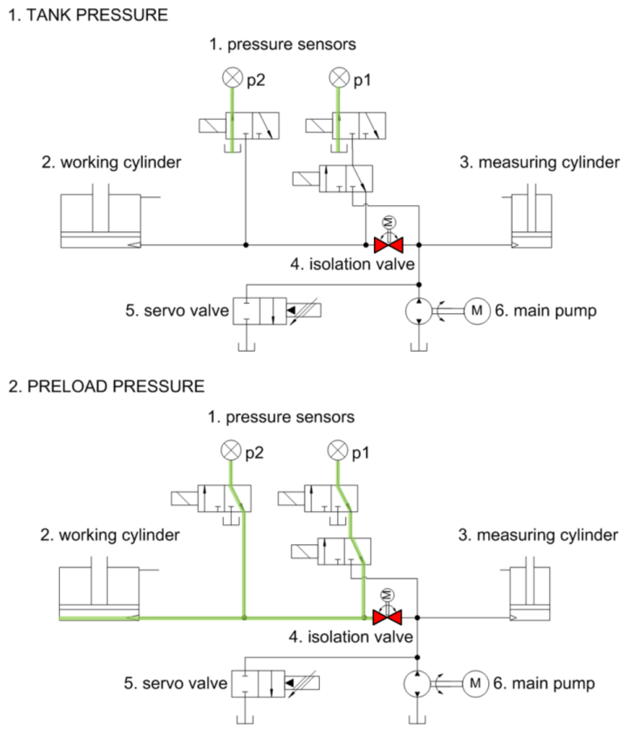

Fig. 2: Pressure sensors p_1 and p_2 connected to 1. tank pressure and 2. preload pressure caused by working cylinder

After preloading sequence, the working cylinder and the measuring cylinder are isolated from each other by an isolating valve (Fig. 3). Hydraulic pressure on working side is measured by the pressure sensor p_2. The hydraulic control unit compares the signals of the pressure sensor p_1 and p_2 and adjusts the servo valve so that pressure difference stays between limit values. In parallel with that, the tare balance is adjusted so that the signal of the displacement sensor is between its limit values. When both signals, pressure difference signal and displacement signal, are stable and within their acceptance level, the tuning has passed the first phase.

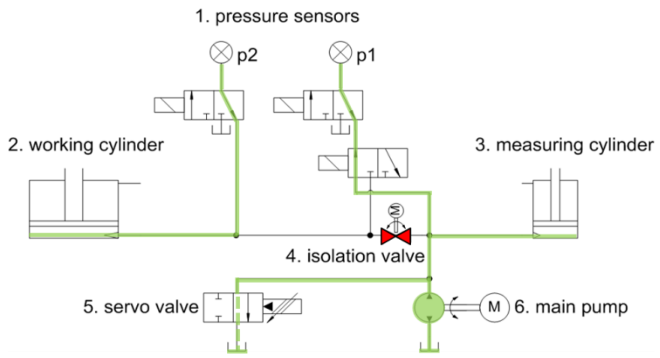

Fig. 3: Pressure sensors p_1 and p_2 isolated by isolating valve

The second tuning phase differs from the first phase by one detail in the preloading sequence. When having preload pressure in both pressure sensors p_1 and p_2, the remaining pressure difference, which was left at the end of first tuning phase, is now adjusted between pressure sensors p_1 and p_2. This is done by adjusting the gain of the pressure sensor's p_1 amplifier. After the second phase of the tuning is passed, the pressure sensors are isolated from main hydraulic pressure line and are not used for control. The machine is ready for operation. A feedback signal for the hydraulic control unit is coming from displacement sensor (9). When loading the measuring cylinder with dead weights (18), the hydraulic control unit is adjusting the servo valve allowing the hydraulic pressure to increase in the main hydraulic line until the signal of the displacement sensor is zero and force equilibrium between measuring cylinder and working cylinder is reached.

4. DATALOGGER & DATAVIEWER

To investigate the machine's functionality and dynamic behavior, there was a need for a measurement system. As a requirement for the measurement system, it should be able to record synchronously all of the analog voltage signals, like displacement sensor signal and control signal of the servo valve, associating to the hydraulic control unit. There should also be a possibility to connect a force transducer into the same measurement system. To realize the functionality of the machine, most important digital input and output lines of the machine's control logic should also be possible to be recorded synchronously. To have a deeper understanding of machine's temperature distribution over operation, the ability for temperature measurements from hydraulic lines was also required. To fulfil all of these requirements, a customized datalogger needed to be developed. The datalogger consists of a commercial real time controller with a Linux operating system running on it. It has six different I/O-modules, overall 50 channels in use, dedicated for recording functionalities of the force standard machine (Fig. 4).

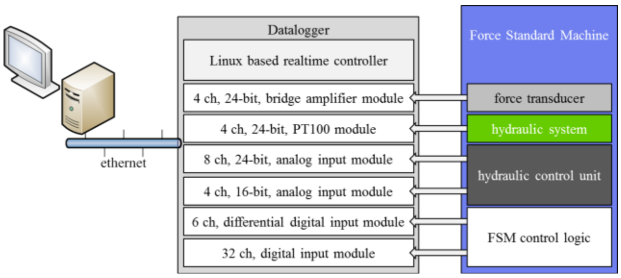

Fig. 4: Functional diagram of the datalogger and its connections

Datalogger can be used by either a remote controller or a remote user interface over the Ethernet connection. The datalogger is programmed using LabVIEW. In the program, input modules are divided into three acquisition loops depending of the maximum acquisition rates of the modules. As a result, the following acquisition rates are used; 50 Hz acquisition rate for digital lines of the FSM control logic and temperature measurements of the hydraulic system, 250 Hz acquisition rate for analog signals of the hydraulic control unit and 500 Hz acquisition rate for force transducer in bridge amplifier module. Because the program has three acquisition loops, also data, including timestamps, is recorded in three different files on the datalogger. To analyze recorded data, a program called Dataviewer is developed (Fig. 6).

Fig. 6: User interface of the Dataviewer program

In the program, it is possible to open all three recorded files for synchronous inspection. Measurement data from the measurement files is loaded in a circular buffer, which size is user defined. Data from the buffer is plotted continuously to the graphs, where user can inspect synchronously measured signals in detail by using cursors.

5. INVESTIGATION OF THE CONTROL SYSTEM

The control system of the 1 MN force standard machine consists of two main units; a control logic and a hydraulic control unit. Communication between these two units is performed by chancing states of the digital input and output channels dedicated for communication. Operation of the control logic and hydraulic control unit can be divided in two main functional modes: tuning mode and loading mode. Both modes should be investigated in detail to get deep understanding of the working principle of the control system. On table 1 the plan for the investigation of the 1 MN force standard machine's control system is presented. To get reliable information about the control system's dynamical behaviour and the hydraulic system's heat distribution on the top of the machines capacity, longer loading sequences were included to the plan. After realizing the plan, total size of the recorded data was over 5 GB. Examples of the results are included in the poster presentation.

Table. 1: Investigation plan for the 1 MN FSM control system

mass stack	nominal force	function of the machine	sequence type
11x10 kN	1 MN	tuning of the machine	
		loading sequence	ISO 376 sequence
		tuning of the machine	
		loading sequence	creep test
		loading sequence	key comparison sequence
11x5 kN	500 kN	tuning of the machine	
		loading sequence	ISO 376 sequence
11x2 kN	200 kN	tuning of the machine	
		loading sequence	ISO 376 sequence

6. CONCLUSION

Before starting the modernization of the control system of the hydraulic amplification force standard machine, a deep understanding of the working principle and the dynamic behavior of the machine has to be reached. The paper presents a method for gathering the essential information about machine functionality for the modernization of the control system. The gathered data has to be analyzed in detail by means of control technic theories to get the control parameters sorted out from dynamic signals of the machine. The presented method will not disregard the importance of comparison measurements of the machine before the modernization of the control system. It only gives additional, more detailed information about the dynamic behavior of the machine.

7. REFERENCES

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