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EXPERIMENTAL MEASUREMENTS OF DYNAMIC BULK MODULUS OF OIL

EXPERIMENTÁLNÍ MĚŘENÍ DYNAMICKÉHO MODULU PRUŽNOSTI OLEJE

Abstract

The experimental measurement and evaluation of the dynamic bulk modulus of hydraulic oil is the object of the paper. We take into account the dynamic bulk modulus during the fast processes taking place in the order of several tens milliseconds. The measurement is done using experimental equipment to measure pressure difference depending on time.

Abstrakt

Předmětem příspěvku je experimentální měření a vyhodnocení dynamického modulu pružnosti hydraulického oleje. Dynamický modul pružnosti uvažujeme při rychlých dějích probíhajících v řádech několika desítek ms. Měření je provedeno pomocí experimentálním zařízení, na kterém měříme tlakovou diferenci v závislosti na čase.

1 INTRODUCTION

Compressibility of hydraulic oils is their significant attribute. The bulk modulus K, which is the inverse value of the compressibility, is a significant factor of these oils. The bulk modulus enters as an important member to the computational models, where it influences mainly the dynamics of the hydraulic system. The value of the bulk modulus is mostly influenced by the amount of non-dissolved air.

2 THE DEFINITION OF THE BULK MODULUS

When is hydraulic oil compressed, the thermodynamic phenomenon determined by the compression rate appears. For slow-going compression it is a isothermal phenomenon that corresponds to the static bulk modulus K_S (line 2). For rapid compression it is a isoentropic (adiabatic) phenomenon and it corresponds to dynamic bulk modulus (line 1) K_D, see Fig. 1 [3].

Static bulk modulus (secant) is defined by relation

$$K_S = \Delta p \cdot \frac{V_0}{V_0 - V} = \Delta p \cdot \frac{V_0}{\Delta V} \tag{1}$$

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Dynamic bulk modulus (tangent) is defined by relation

$$K_D = V \cdot \frac{dp}{dV} \tag{2}$$

where:

V_0 – original volume of oil [m^3],
V – volume of oil after compression [m^3],
ΔV – difference of oil volume [m^3],
Δp – pressure change [Pa].

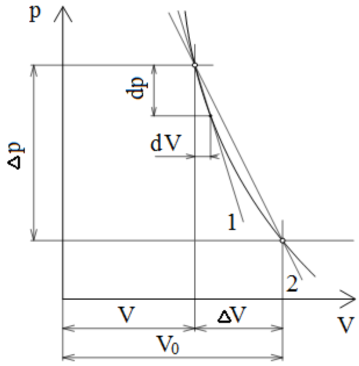

Fig. 1 Definition of static (line **2**) and dynamic (line **1**) bulk modulus of oil.

3 DESCRIPTION OF EXPERIMENTAL DEVICE AND MEASUREMENT

The device, used for the experiment, consists of a hydraulic aggregate, pipe, directional valve and stop valve, see Fig. 2.

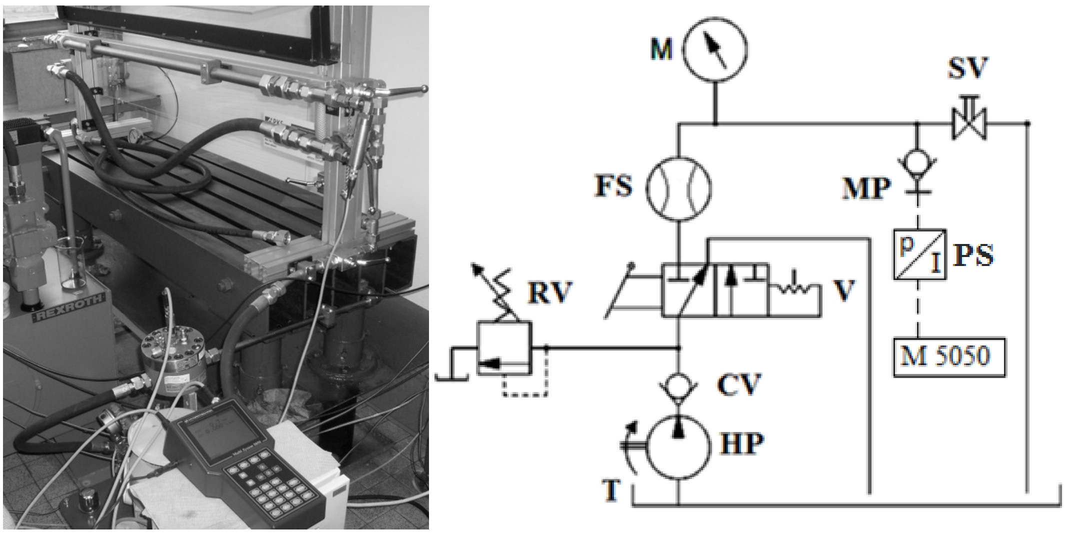

Fig. 2 Photo of experimental device and its simplified scheme.
(**Legend:** CV - check valve, FS - flow sensor, HP - hydraulic pump, M - manometer, MP - measuring point, PS - pressure sensor, RV - relief valve, SV - stop valve, T - tank, V - directional valve).

The characteristic Δp – Q of hydraulic pump **HP** was measured at the first, see Fig. 3. Flow at a certain pressure gradient is read from this characteristics. The measurement procedure is following. Required pressure is set the on relief valve **RV**, the valve **V** is converted and the flow is transferred into the whole circuit. Oil flows through steel pipeline located between flow sensor **FS** and stop valve **SV**. The steel pipeline consists of two parts, which have a different dimensions. Pipeline 1 length is 3.42 m with inner diameter 0.012 m and pipeline 2 length is 1.73 m with inner diameter 0.022 m. Next, the valve **SV** is closed and in measuring point **MP** is measured increase of pressure in pipeline during time, see Fig. 4. Measurement is performed by using measuring device Hydrotechnik M5050 and pressure sensor **PS**. Measurement proceeded for oil temperature t_t = 30°C [1].

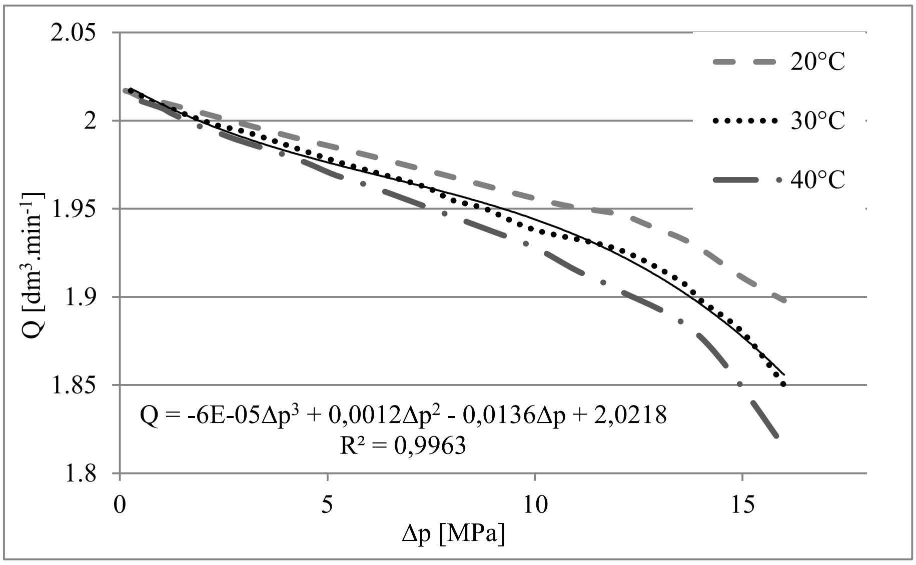

Fig. 3 Δp – Q characteristics of hydraulic pump **HP** (above mentioned equation is valid for temperature t_t = 30°C).

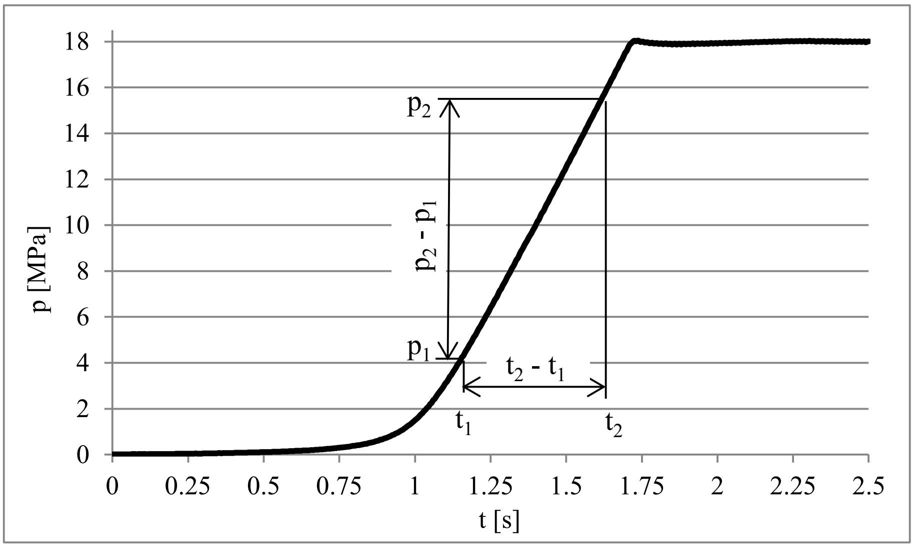

Fig. 4 The increase of pressure p depending time t.

4 METHOD OF CALCULATION

The dynamic bulk modulus is calculated by the formula (3), where the flexibility of pipe is also taken into account:

$$K_D = \frac{1}{\frac{\Delta V}{V_0 \cdot (p_2 - p_1)} - \frac{d}{E \cdot s}} \tag{3}$$

Change of the volume is given for the calculation of dynamic bulk modulus as

$$\Delta V = Q \cdot (t_2 - t_1) \tag{4}$$

where:
Q – flow rate [$m^3 \cdot s^{-1}$],
d – inner diameter of pipe [m],
s – pipe wall thickness [m],
E – modulus of elasticity of steel [Pa],
p_1, p_2 – pressure in the beginning and in the end of process [Pa],
t_1, t_2 – time in the beginning and in the end of process [s].

Flow rate Q is read from the measured Δp – Q characteristics of hydraulic pump **HP** at temperature t_t = 30°C, see Fig. 3. This characteristics was measured so as it is possible to calculate exactly the flow at the desired pressure and temperature.

5 THE MEASURED AND EVALUATED DATA

Table 1 shows an example of measured and calculated data. The first column shows the pressure p, which is set on the relief valve **RV**. V_0 is the volume of oil before compression, which is between hydraulic pump **HP** and the stop valve **SV**. The hydraulic oil is enclosed mainly in a steel pipeline, the influence of the hose between the flow sensor **FS** and the directional valve **V** is negligible. The pressure change p_2 - p_1 is read only in linear part of the curve, which is evident from Fig. 4. For all measurements was the initial pressure value p_1 = 1.5 MPa.

Tab. 1 Measured and calculated data.

p	V_0	$p_2 - p_1$	ΔV	$t_2 - t_1$	Q	K_D
[Pa]	[m^3]	[Pa]	[m^3]	[s]	[$m^3 \cdot s^{-1}$]	[Pa]
9.00E+06	2.13E-03	7.5078E+06	1.18E-05	0.36	3.28E-05	1.40892E+09
1.20E+07	2.13E-03	1.0577E+07	1.58E-05	0.485	3.25E-05	1.49167E+09
1.50E+07	2.13E-03	1.3617E+07	1.93E-05	0.605	3.2E-05	1.56724E+09

Figure 5 shows the dependence of dynamic bulk modulus on pressure change p_2 - p_1. Lower values of dynamic bulk modulus are probably caused by content of air bubbles.

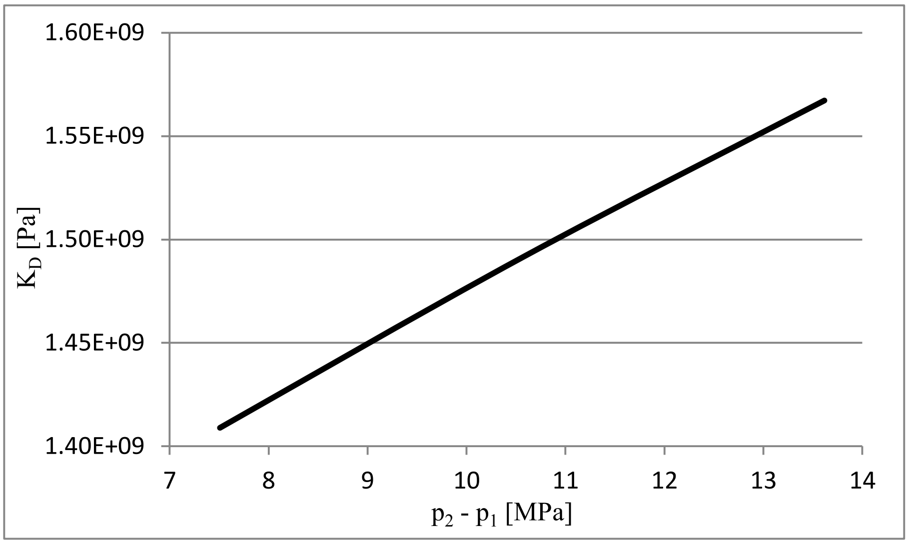

Fig. 5 Dependence of dynamic bulk modulus on the pressure change $p_2 - p_1$.

6 CONCLUSION

An experimental device for measurement of dynamic bulk modulus of oil was described in this paper. Δp – Q characteristics of hydraulic pump was measured as the first. Next, it was measured change of pressure during time, when the valve was closed at the pipeline outlet. Dynamic bulk modulus of oil was calculated from the measured values. The bulk modulus depends except of pressure also on air bubbles and oil temperature.

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