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A METHOD OF INVESTIGATING INTERNAL LEAKAGES IN AIRCRAFT HYDRAULIC UNITS

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Abstract

Methods of diagnosing technical condition of aircraft hydraulic systems have been analysed. Associated precision pairs of aircraft hydraulic systems have been presented. The most essential features of operating conditions and the loads that affect distributor components of sliding pairs have been identified. The structure of BU intensifier with a sliding distributor has been illustrated. Equation for internal leakages for a precision hydraulic pair with a concentric annular gap (clearance) has been presented. Illustrated and discussed are instances of examining internal leakages occurring in hydraulic systems (with direct methods applied). Findings of research into these issues have been presented as based on measurements taken on the hydraulic system of the Su-22 operated by the Air Force of the Republic of Poland. The technique of examining the problem consists in taking and recording measurements of the drop in pressure in the hydraulic system. The relationship between time of pressure-drop and total leakage for hydraulic systems of particular Su-22 aircraft has been illustrated. The results of research direct and indirect methods have been presented and analysed. Both methods have been compared from the aspect of assessing technical condition of the aircraft hydraulic system. Potential factors that could affect measurements with a given method have been identified.

Keywords: *aircraft hydraulic unit, internal leakage, precision hydraulic pair*

1. Introduction

One of ITWL's (Instytut Techniczny Wojsk Lotniczych – Air Force Institute of Technology) areas of interest is research into changes (consumption) of service life of aeronautical equipment/ systems in the course of their operation. One of research methods is predicting the service life still left by observing changes in values of structural parameters measured throughout the operational process [2]. The 1st and the 2nd hydraulic systems of the Su-22 are objects under examination.

To estimate service lives of the Su-22's hydraulic systems, used is a method that offers two points of view to assess life of a drive or a hydraulic system: the first one consists in the assessment of the limited time of operation, which results in the Fail-Safe Operation Time, whereas the second one – in the assessment of the monitored operation time, the latter being based on the periodically taken measurements of the process of deterioration in parameters of monitored hydraulic systems and components thereof. The method has been based on the estimation of service life at the level of permissible value (limited service life) and determination of the relationship(s) between values of preset tolerances of the monitored parameter and periodicity of checks, at some pre-set level of non-damageability provided. The preset tolerances make up a set of check parameters, which comprises values between the boundary and permissible limits. If a check parameter exceeds the boundary limit, it means the hydraulic system/a component thereof suffers a damage/failure [2, 3, 10].

The research into changes (consumption) of service life is to evaluate technical condition of the 1st and the 2nd hydraulic systems/components thereof, and whether their functional parameters comply with those required by the Specifications; also, the degree to which the service lives of hydraulic system/components thereof have been consumed. Another objectives to follow the above-mentioned ones are as follows: to analyse the degree of deterioration in structural parameters of these systems, to find the gradient of measured parameters and to compare it with boundary values, an finally, to state whether further operational use of the hydraulic system/components thereof is possible, or – if boundary values of structural parameter have been exceeded – to qualify the selected hydraulic system component(s) as one(s) to be replaced by new or overhauled item(s) [2].

One of the most important structural parameters taken into account while examining components of hydraulic systems, e.g. hydraulic intensifiers, electro-hydraulic servo valves, is internal leakages.

2. Characteristics of a precision hydraulic pair

A hydraulic intensifier is a hydro-mechanical servo system with a symmetric linear actuator of two-way operation. It is provided with a rotary slider that consists of distributing plates. Each of two actuator cylinders is powered simultaneously from one out of two separate hydraulic systems; if a failure occurs to one of the systems, the intensifier continues operation, however, with only one cylinder being powered, and with only half of the maximum power available when both cylinders are power supplied [8, 9]. Aircraft control intensifiers are also the most heavily loaded components of the hydraulic system since they suffer excitations from changes in aerodynamic loads (forces) affecting the fin, tail plane and aileron surfaces. Because of its structure, the hydraulic intensifier is featured with the highest value of an internal leakage among all structural components of a hydraulic system; what is more, it suffers the highest wear-and-tear throughout the aircraft operational use. Flight safety requires the hydraulic intensifier to show steady operation, i.e. after any disturbance or trouble it should recover and remain stable, irrespective of the source and value of the disturbance [10].

Various types of solutions for the distributing component find their application in hydraulic intensifiers. One of is a sliding distributor with a cylindrical slider that keeps in linear oscillating to-and-from motion against the cylinder with slight displacement [2, 4, 5, 11]. Fig. 2.1 shows a schematic diagram of the sliding distributor with a cylindrical slider, which is fitted on the hydraulic intensifier BU.

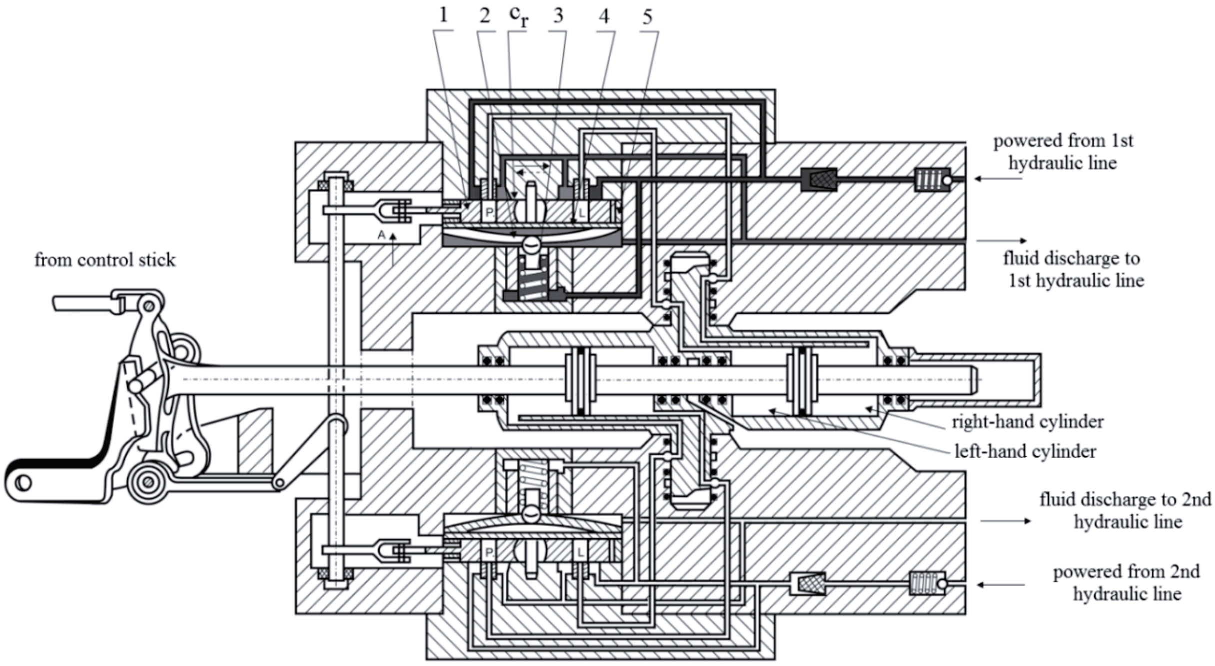

Fig. 2.1. Cross-section of the BU intensifier with a sliding distributor, with hydraulic fluid flow paths marked in: dark gray – power, light gray – fluid discharge, 1 – distributing disc, 2 – thrust washer, c_r – running clearance, 3 – spring, 4 – flat washer, 5 – stopper ring [8, 9]

The most essential feature of operating conditions and the loads that affect distributor components of sliding pairs is that any relocation/shift of the slider against the cylinder sleeve takes place periodically, by manual or electrical excitation, irrespective of the hydraulic fluid's pressure and stability. The slider of the distributing sliding pair is affected by:

a) friction forces between the slider and the sleeve,
b) hydrodynamic forces (radial forces) resulting from the hydraulic fluid flow through the clearance between the slider and the sleeve due to differential pressure,
c) friction forces resulting from the obliteration in the (structural) clearance,
d) axial forces.

Due to all these forces specific resistances occur to counteract the change in slider's position against the cylinder. Apart from the above-mentioned forces, the slider may also be affected by friction forces due to impurities getting into the running clearance c_r (Fig. 2.1) of the precision pair in question [10, 11].

3. Direct method of examining internal leakages in hydraulic units

The degree to which hydraulic components suffer wear-and-tear is, in practice, evaluated by means of measuring internal leakages that occur inside of them. Such measurements can be taken on special-purpose testing stand. For actuators and hydraulic motor one can take measurements with no need to dismount the items. In the case of an actuator/servomotor, one has to move the piston in any extreme position. With the hydraulic power connected all the time to the actuator's cylinder filled with the hydraulic fluid, one can disconnect the second discharge conduit from the whole system and put it in the measuring cylinder. The same situation takes place with the hydraulic motor burdened with a power unit: the leakage discharge pipe, or anything like this, should be directed to the measuring cylinder. In both the cases time for filling a preset volume with a fluid is measured and leakages calculated. The measurements should be now compared with catalogue data. The results obtained in this way give us good grounds to assess the degree of wear of checked components [1].

Measurements of internal leakages in particular components of the hydraulic system of the Su-22 are among many and various diagnostic works carried out at ITWL to determine the degree of components wear-and-tear. The diagnostic work is carried out with no hydraulic component being dismounted from the aircraft. Supply is provided by the airfield hydraulic energy source [2]. It consists in taking measurements of the internal leakage at extreme positions of actuators (hydraulic servomotors, hydraulic intensifiers) and at service positions of electro-hydraulic distributors. At the stage of evaluating, the degree of the hydraulic component's wear a comparison is made between the measurement of the rate of internal leakage taken and the maximum leakage shown in the Specifications. This gives grounds for evaluation of the degree of the hydraulic component's wear and its suitability for further operation on a given aircraft, or – if permissible values of the leakage have been exceeded – decision is taken to send the component under examination away for recovery.

Figure 3.1 shows several instances of how internal leakages in hydraulic intensifiers on the Su-22 are examined by the ITWL's specialists.

4. Indirect method of examining internal leakages in hydraulic unit

What matters in the indirect method is value of time of the pressure dropping in the hydraulic system measured between boundary values of pressure. The airfield hydraulic supply system, the same as with the direct method, is a source of hydraulic energy.

The time of pressure dropping in the hydraulic system depends on the amounts of internal leakages in all the supplied units. Internal leakages are determined, first of all, with all the clearances in precision hydraulic pairs. Apart from that, they strongly depend on:

– temperature of the hydraulic fluid,
– kinematic viscosity,
– density.

a)

b)

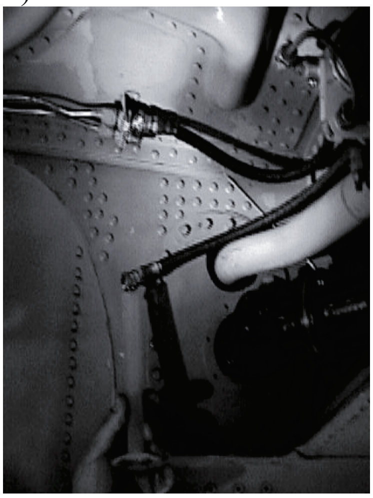

Fig. 3.1. Photos showing measurements of internal leakages taken by ITWL experts on the Su-22 (a – measurement of internal leakage in hydraulic intensifier the fin, and b – internal leakage in the actuator of the main landing gear leg)

Equation for internal leakages q_v [cm^3/min] for a precision hydraulic pair with a concentric annular gap (clearance) takes the form [7]:

$$q_v = 5 \cdot 10^3 \cdot \frac{(p_l - p_0) \cdot \pi \cdot d_1 \cdot c_r^3 \cdot \rho\left(\frac{p_l + p_0}{2}\right)}{\mu \cdot l_c \cdot \rho(0)}, \text{ [cm}^3\text{/min]}, \quad (1)$$

where:
p_l – hydraulic line supply pressure [MPa],
p_0 – pressure at the side of leakage [MPa],
d_1 – diameter of the hydraulic component in the precision pair [mm],
c_r – hydraulic clearance in the precision pair [mm],
ρ – density of hydraulic fluid [g/cm^3],
μ – dynamic viscosity of hydraulic fluid [Pa·s],
l_c – distance of contact of a component in the precision pair with cylindrical surface [mm].

In the method in question, value of time of pressure-drop t_s that depends on value of total internal leakage Q_V in the hydraulic system is a diagnostic parameter. The pressure-drop time is measured for some specific range of pressure values Δp (Fig. 4.1). The change of value of pressure-drop time t_s against $t_{s(0+n)}$ results from the increase in clearance in the precision hydraulic pair as it suffers wear-and-tear in the course of operational use between subsequent examination efforts. Change in time of pressure-drop Δt_s in some specific range of pressure values:

$$\Delta t_s = t_{s(0+n)} - t_s \quad \text{[s]}, \quad (2)$$

where:
$t_{s(0+n)}$ – time of pressure-drop in some specific range of values for initial examination [s],
t_s – time of pressure-drop in some specific range of values for subsequent examination effort [s].

While operating an aircraft hydraulic unit, value of the clearance in the precision pair increases. This quantity includes the constructional clearance and an increment in the clearance due to the wear-and-tear resulting from the operational use of the hydraulic unit.

$$c_r = c_m + \Delta c_e \text{ [mm]}, \quad (3)$$

where:
c_m – constructional clearance [mm],
Δc_e – clearance increment due to the wear [mm].

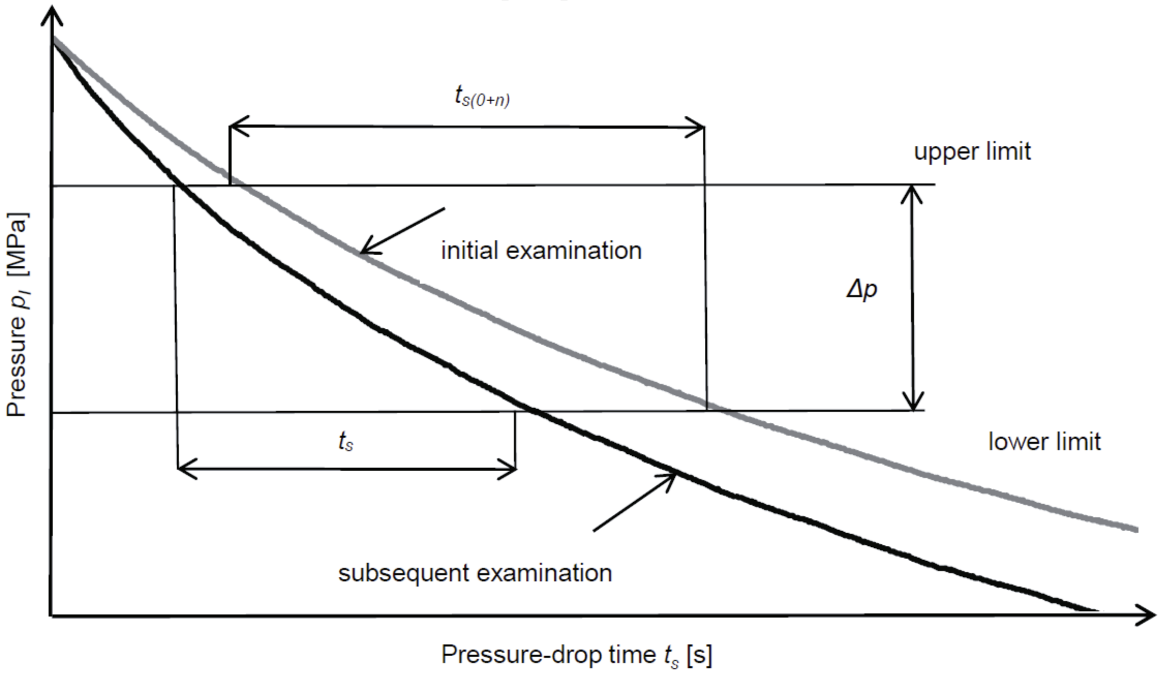

Fig. 4.1. Characteristic curves for time of pressure-drop $p_l = f(t_s)$ in the hydraulic system

The clearance increment Δc_e resulting from the wear-and-tear of the precision hydraulic pairs due to the operational use (from the initial examination to the subsequent one) causes that the time of pressure-drop in the hydraulic system is reduced – ($t_s<t_{s1}$) – Fig. 4.2. What is more, the value of the time of pressure-drop refers to the whole hydraulic system, but not to particular structural components thereof. Value of the diagnostic parameter is compared with data acquired with direct methods.

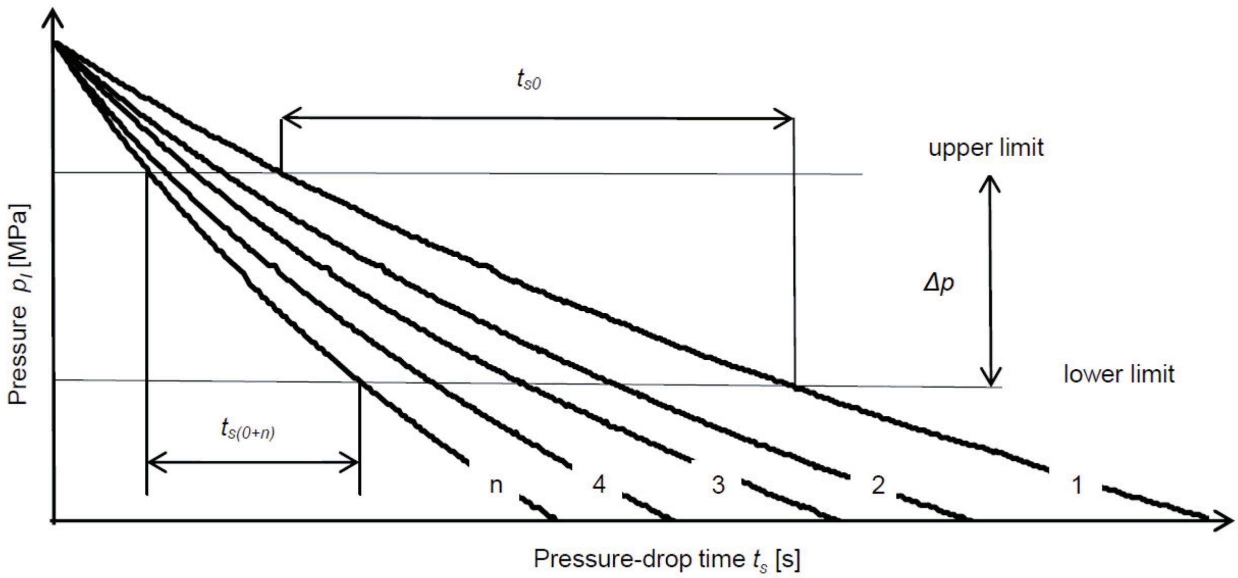

Fig. 4.2. Family of characteristic curves for time of pressure-drop $p_l = f(t_s)$ in the hydraulic system

The trend function $t_{si} = f(Q_{Vi})$ is constructed using measurements taken with both direct and indirect methods. Each value of pressure-drop time t_{si} corresponds with the value of total internal leakage in the hydraulic system Q_{Vi}. Values of A, B, and C coefficients depend on measured values, on the basis of which the form of the trend function is determined (Fig. 4.3).

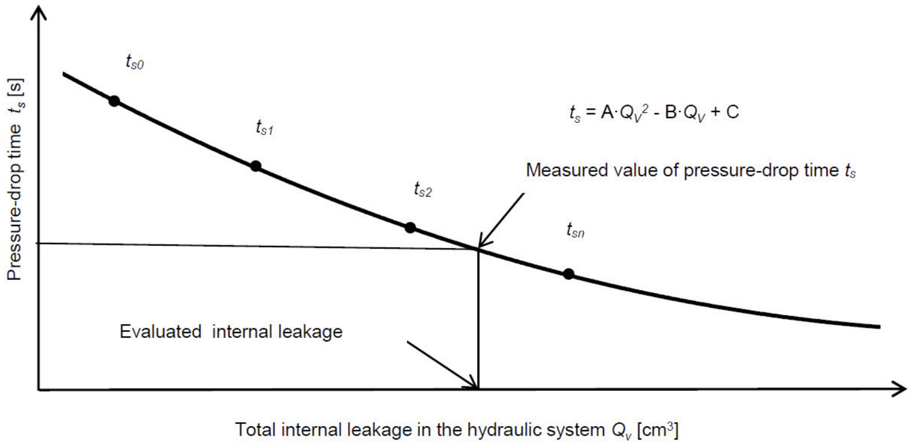

Fig. 4.3. Trend function $t_{si} = f(Q_{Vi})$ of change in the pressure-drop time depending on the total internal leakage in the hydraulic system

5. Measurements with direct and indirect methods

One of ITWL's (Air Force Institute's of Technology) areas of interest is research into changes (consumption) of service life of an aircraft hydraulic system in the course of its operation. Examination of the Su-22 hydraulic systems and components thereof consists in determination of opportunities of extending calendar-based service lives of the 1st and the 2nd hydraulic lines. The effort has been aimed at evaluation of technical condition of both the hydraulic lines and components thereof with reference to compliance of functional parameters with requirements formulated in the Specifications; also, at finding the gradient of measured parameters and comparing it with boundary values (limits) [2, 3]. Two methods, i.e. direct and indirect ones, have been applied to measure internal leakages in the course of examining the Su-22 hydraulic systems. Since the indirect, method finds its applications to estimate the total internal leakage in the whole hydraulic system under examination, the summation of internal leakages measured in particular hydraulic units has been carried out with the direct method to then compare both the methods. Fig. 5.1 presents findings for five selected Su-22 aircraft, whereas Fig. 5.2 shows curves plotted for pressure-drop within the range of pressure given consideration, for exactly the same aircraft.

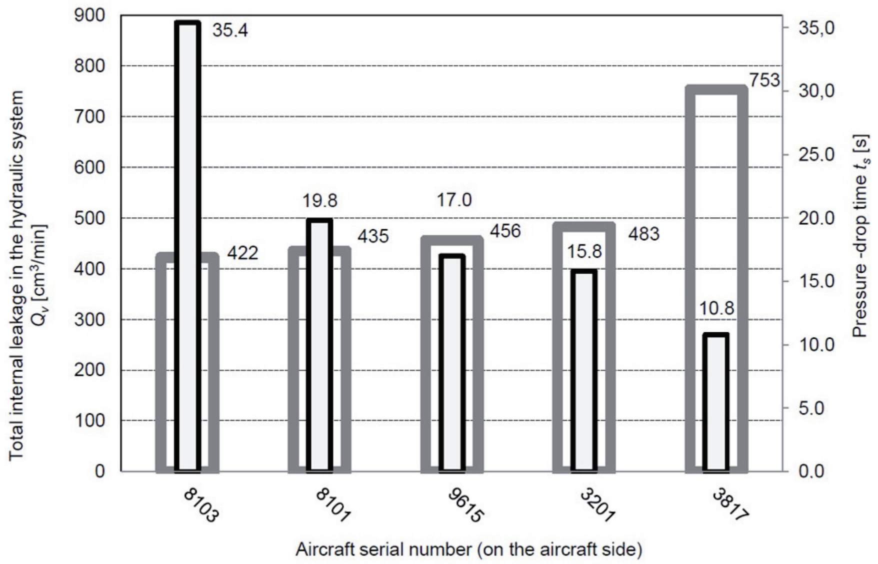

Fig. 5.1. Total leakage and pressure-drop time for hydraulic systems of particular Su-22 aircraft

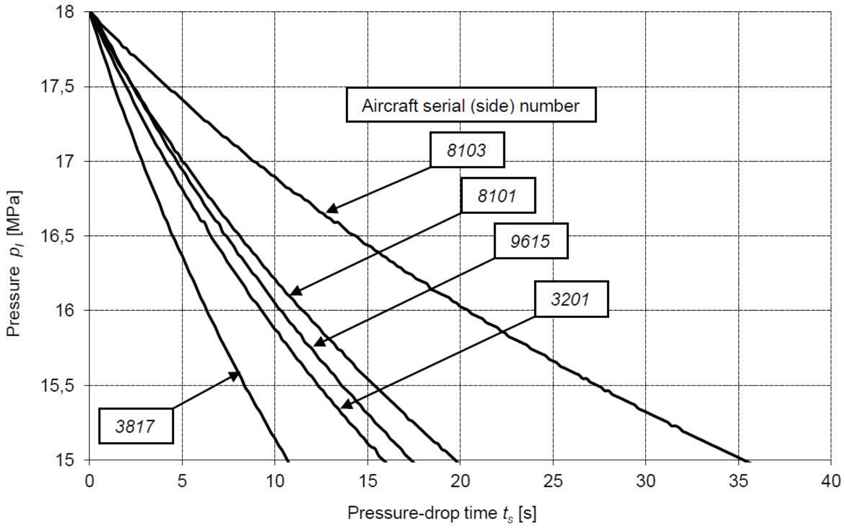

Fig. 5.2. Pressure-drop curves gained with indirect method of estimating total leakages in the Su-22 hydraulic system

6. Recapitulation

A traditional method of evaluating the technical condition of any unit of the hydraulic system consists in the determination of the amount of internal leakage with a direct method. This method needs, however, the structure of the hydraulic system to be interfered, i.e. conduits of the discharge portion of the system have to be dismounted. Another disadvantage of the direct method is loss of the hydraulic fluid. On the other hand, the indirect method allows of the evaluation of internal leakages in the whole hydraulic system, which is extremely advantageous when aircraft hydraulic systems are subject to condition-based maintenance. This enables monitoring of the hydraulic system's technical condition. Considerable benefits result also from the fact there are no losses of the hydraulic fluid. Such losses occur while finding leakages with the direct method. It should be emphasized that the indirect method provides estimates of total leakage in the hydraulic system as a whole, not in particular units/components thereof. On the basis of the accomplished work, it has been stated that both the methods remain complementary to each other.

Factors that affect measurements of internal leakages gained with both the methods are as follows: temperature of the hydraulic fluid, viscosity at temperature in question, and control stick set up in appropriate positions.

What has also been noticed is a relationship between the time the pressure-drop in the hydraulic system takes and the total internal leakage.

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