In designing pressure transducers whose hermetically sealed cavity between two elastic sensing elements (sheaths or diaphragms) is filled with a liquid, it is necessary to determine the pressure between the elastic elements with respect to the value of the measured pressures.

For the solution of this problem it is necessary to know the volume of the liquid ejected during the operation of the sheaths. These data do not exist in handbooks and are not cited in technical documents on elastic sensing elements (bellows, diaphragms, etc.).

Keningsberg [1] recommends experimental determination of this value for each possible case: of a concentrated load and loading by means of the medium (with and without a spring and with the sensing element resting against the stop). These experiments require the manufacture of reference springs and special equipment suitable for such testing of elastic sheaths. For designing these springs it is necessary to know the stiffness of the sensing element (bellows) whose selection may depend on the results of testing.

Let us attempt to determine the expelled volume of the liquid analytically with the required precision. The selection of the bellows' durable characteristics and the tentative computation of the additional error due to measuring the pressure in the intermediate cavities filled with the liquid [1] does not require high precision in measuring the ejected volume of liquid. The error of each transducer is determined by calibrating it. The large dispersion in technological allowances for the diameters of crimps (± 2.5%) and for the thickness of the bellows material (up to ± 10%) lead to a large dispersion in both the experimental and computation results. Therefore, the error in determining the volume of the expelled liquid should be smaller than that due to the possible deviations in dimensions.

The most general type of loading of a bellows consists of its operation with a spring under the pressure of a medium.

Let us assume that the volume \( \Delta W_m \) of the liquid expelled in the operation of the bellows with a spring under the pressure \( P \) of the medium consists of two quantities:

\[
\Delta W_m = \Delta W_S + \Delta W_0,
\]

where \( \Delta W_S \) is the volume of the liquid expelled by the bellows' displacement \( S \) under the effect of a concentrated force; \( \Delta W_0 \) is the volume of the liquid expelled by the pressure \( P \) of the medium on the bellows, which was previously compressed along its axis by the amount \( S \) up to its stop.

Let us assume that under the effect of the concentrated force the straight parts of the crimps retain their linearity, and the quantity \( \Delta W_S \) is formed mainly by the variation of the slope angle \( \alpha \) of these straight parts with respect to the cross section. Let us assume that \( \Delta W_0 \) is formed by the curving of the straight parts of crimps under the effect of a uniformly distributed pressure. If we assume that the value \( \Delta W_0 \) does not depend on the angle \( \alpha \) (within its variations from 0 to 10°), then \( \Delta W_m \) can be determined as the sum of two quantities each of which can be calculated and measured.

A relationship (1) was confirmed with deviations not exceeding ± 3% by testing the external pressure of bellows made from beryllium bronze [2] 21 x 15 x 0.12, 21 x 13 x 0.92, 28 x 5 x 0.12, and 28 x 4 x 0.16.
A single-bellows pressure transducer with an inductive converter (Fig. 1) was adapted for such testing.

The expelled volumes of liquid were measured with respect to variations of the liquid level in the glass tubes. Since small diameter tubes were used in measuring small volumes, the error in measuring the level did not exceed 3%.

For measuring the pressure $P$ a reference class 0.4 manometer was used. The bottom of the bellows was displaced by an amount $S$ by means of the micrometer screw 13. The measurement error did not then exceed 0.02 mm.

The displacement of the bellows bottom under the effect of the pressure $P$ of the medium was measured on an inductive transducer with an error not exceeding 1%. Measurements of displacements under pressure were used for computing the sensing element's stiffness. The value of $\Delta W_q = f(P)$ was evaluated experimentally at the stop for various compressed lengths of the bellows.

The deformations of the stop were checked by means of the same inductive transducer with an error not exceeding 0.01 mm. This was taken into consideration in processing the experimental data. For small expelled liquid volumes $\Delta W_q$ (stiff bellows) we also took into account the effect of the liquid-filled cavity volume changes produced by the transmission of the force exerted on the stop to the bottom of the casing. The screw 13 was used for transmitting a force equivalent to the pressure which was not exerted (thus obtaining the same deformation) and the change of the liquid level in the glass tube was measured. The inductive transducer was calibrated by means of a clock-type indicator with a scale value of 0.01 mm.

The expelled volume $\Delta W_S$ of liquid due to the effect of the concentrated force was determined both experimentally and analytically.

Let us examine the relationship $\Delta W_S = f(S)$ produced in compressing the bellows.

Let us adopt the notations of the quantities shown in Fig. 2 and assume that it is possible to neglect changes in the size of the diameter and the mean radius $R$ of crimps produced by stresses within the elasticity limit. Calculations have shown that the relative changes in these dimensions at a pressure of $10^9$ Pa is smaller than 1% for beryllium bronze. By assuming that the volumes of the shaded parts shown in Fig. 2 do not change when the bellows is deformed, that $\alpha < 10^6$, and that $\cos \alpha = 1$, and by adopting intermediate notations $R_c$ as the distance of the center of gravity of the triangle abc to the bellows axis and $n$ as the number of waves (crimps), we shall find after simple transformations that

$$\Delta W_M = \frac{\pi S}{4} \left( \frac{D_e - 2R - h}{3} - \frac{2D_e + D_i - 2R - h}{3} \right).$$

Computations have shown that a close approximation is obtained by calculations from the formula

$$\Delta W_S = SF = \frac{\pi S}{4} \left( \frac{D_e - D_i}{2} \right)^2,$$

where $F$ is the effective bellows area.