PRESSURE FLUCTUATION MEASUREMENTS ON LARGE-SIZE WATER TRANSMISSION LINES, AND THE EXPERIENCES GAINED THEREBY

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I. Introduction

On the Budapest Hydraulic Engineering Conference which took place in January, 1962, the target requirements set by this research group at the beginning of the development work aiming at the construction of instruments and equipment suitable for pressure fluctuation test purposes, had been outlined in details.

At that time, all the instruments and measuring equipments developed so far, as well as the results and experiences of measurements made up till then had been reported on [1]. It was announced that the task consisted of constructing a measurement apparatus which would enable, by making use of the existing fundamental equipment, the simultaneous measurement and registration of pressure fluctuations at several points, located even at considerable distances from each other, if required. The true and distortion free registration of the pressure process was also stipulated. Now the results of our recent activity conducted meanwhile in this field, and some of our experiences deserving general interest will be summarized briefly.

As is well known, these studies were carried out not only for their scientific character but as co-ordinated to the respective industrial requirements, thus making the results of the work completed immediately adaptable in practice besides permitting the collection of measurement data, on large-size pipe lines operated under actual conditions, to be processed later. Series measurements performed with two different pipeline types will be reported on: the pump and pressure line assembly of the water supply system of a large-scale industrial establishment had to be tested in the two cases. The industrial objective was to provide for the basic numerical data supported by actual measurement results as requested for plant operation directives. Our main interest was concentrated on the operational specification details concerning plant and pipeline system safety, with the possibility of a power supply breakdown also taken into consideration. The simplified layout scheme of the two plants is illustrated in *Fig 1.*

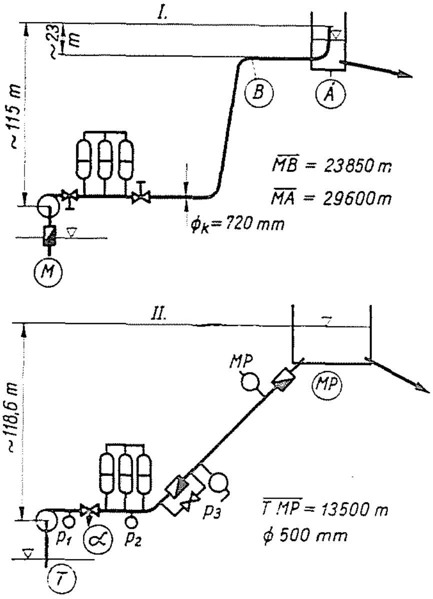

Fig. 1

II. The setup of Plant I

In Plant **I**, water is taken up by the pump through an inlet-side back pressure valve and delivered, via an electric and/or manual gate valve into the 702/720 mm diameter delivery duct of about 30 km length. Here the line joins an upright, with the gravity flow of the water therefrom. Beyond the delivery gate valve, there are 3 pressure tanks parallelly connected to the discharge line. The pipeline is equipped, of course, with a number of other fittings as well, like discharge and bleeder vents, manholes, etc, which are not shown in the Figure as having no direct interest for the present investigation. The plant has 3 different sized pumps connected to the line in order to deliver $Q_{4/4} = 500$ lit/sec, $Q_{2/4} = 250$ lit/sec, and $Q_{1/4} = 125$ lit/sec water quantities, respectively, into the system as required. Accordingly, operational pressure head figures were $H_{4/4} = 220$ m, $H_{2/4} = 141$ m, and $H_{1/4} = 121$ m, respectively.

In course of the measurements, the $p = f(t)$ process at points **M** and **B**, was studied in case of consecutively excluding each of the different capacity pumps and with 3, 2, and 1 pressure tanks, respectively, connected. In addition, the $n = f(t)$ pump-speed curve and the water level variations in the respective pressure tanks have also been registered.

In order to determine wave propagation velocity in the line, sudden start and stop tests have been performed by using pump $Q_{1/4}$ with the gate valve choked, that is, under reduced water delivery conditions, and without pressure tanks which represented an "inelastic oscillating system". All these measurements were completed partly in August, 1962, and partly in November, of the same year. The test points and the measurement centre had a telephone connection in between.

III. The setup of Plant II

According to *Fig. 1*, essentially this plant was similar to Plant I. Field condition differences are revealed (in a simplified manner) by the scheme. Pumps of only two different transfer capacities could be employed here for the 500 mm diameter pressure line: $Q_{4/4} = 440$ lit/sec, and $Q_{2/4} = 250$ lit/sec. Pressure head values were $H_{2/4} = 140$ m and $H_{4/4} = 190$ m, respectively. Water was delivered into the pressure line through an electric/manual ring valve stem which could suddenly close *(automatically)* with an adjustable delay, in case of a power supply breakdown, upon the load effect. The 3 pressure tanks are connected to the subsequent pressure line section whereafter the water flows through a back-pressure valve located in a by-pass to the upper reservoir at a distance of 13.5 km. Waterflow is by gravity therefrom. Prior to entering the upper tank, the pressure line has another back-pressure valve inserted to prevent potential counterflow, not to mention the other operational fittings neglected in this study. Similarly, phenomena tested with Plant I have also been investigated here. As a further task, ring valve stem delay had to be adjusted to prevent, in case of a power supply breakdown, the reverse speed of the "small-size" pump $Q_{2/4}$ exceeding the operational value. These measurements were completed in the summer of 1963. Test points and measurement headquarters had radio communication.

IV. Description of the measuring equipment

Since each variable had to be registered in function of time, the signals were registered by means of loop oscillographs.

The instruments employed included the RFT-SO3 paper type 3-loop and the N3 film type 8-loop oscillographs.

Time signal was supplied by a Jacquet 30 sec electric signal stop-watch carefully calibrated for reasons to be explained later. Calibration was performed at an ambient temperature within the range from $-5°$ C to $+40°$ C. The maximum difference in the aforesaid range amounted to $17 \cdot 10^{-3}$ sec below 30 sec. (Measurements were made by means of a *Disa II* electronic counter.) Error $2f$ amounted to the value $2f = 17/30{,}000 = 0.567^0/_{00}$ which, meaning $f = \pm 0.28^0/_{00}$, represented a very favourable figure. Since the paper-tape speed employed amounted to about 5 mm/sec, the line thickness of about

1/10 mm represented an evaluation error of $1/1500 = 0.666^0/_{00}$ as compared to the 150 mm conforming to the 30 sec figure.

Speed variations were registered by recording the voltage of a direct current speed generator. Stabilized values were determined by means of a separate tachometer.

The instant of other phenomena such as switch-off was recorded by marks along the time signal line.

Pressure measurements made at various predetermined points of the line were performed by means of an in-plant produced steel membrane transmitter head manufactured in conformity with the respective pressure limit *(Fig. 2)*. Pressure value variations were converted to electric resistance variations by using 4 strain gauges mounted on the membranes. It will be noted here that, on the basis of literature data, plexiglas pressure gauges have also been produced (see *Fig. 3)* permitting the pressure gauge head of not excessively thin membrane — which could be readily produced even under low pressure value conditions — to render satisfactory amplitudes on the oscillograph screen.

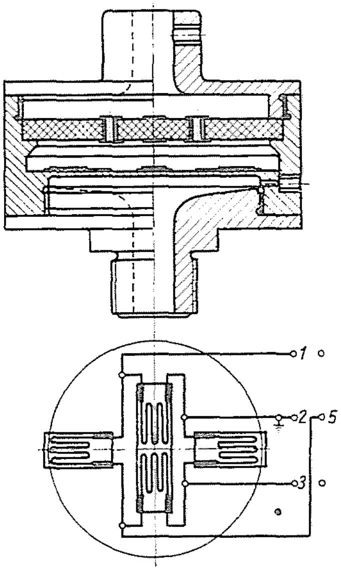

Fig. 2

Now after having collected test experiences of an extended period of time, the following facts might be stated: if mounting the stamp onto the steel membrane is performed according to the usual specifications and with normal care, clear linear deflections will be obtained, practically stable in time within the pressure range specified for the membrane, even with the membrane maintained under load for an extended period of time.

Unfortunately, the same is not true in case of a plexiglas membrane although which, produced properly, would render a linear amplitude easy to calibrate but, under continuous load conditions and after an extended period of time, the membrane might undergo a permanent deformation resulting, as expressed by indication, in a zero-line drift and, subsequently, in the disappearance of linearity. This means certain limitations to its application.

A further problem was represented by the development of the transmitter head used for registrating water level in the pressure tank. Here variable signals of full screen width representing $2 \div 3$ m water head pressure fluctuations were sought for under the prevailing water and air pressure conditions of about $p = 20$ atm overpressure. The problem is complicated by the requirement of protecting the gauge side from water.

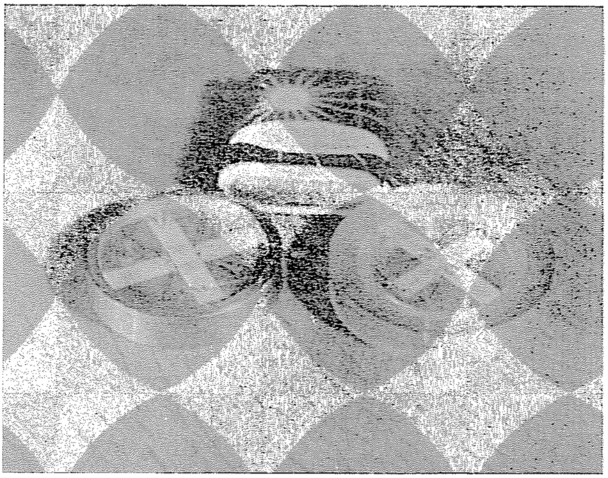

Fig. 3

This problem was solved by means of a steel membrane similar to that illustrated in Fig. 2 with pressure-tight seals provided for both sides, one for connecting the water side and the other the air side. The membrane proper was turned to a thickness of $b = 0.3$ mm from a single work. Since such a thin membrane may be loaded up to about 1 atm overpressure, its connection was developed according to the scheme illustrated in *Fig. 4*. This reveals a so-called split face cut out of aluminium foil which was located parallel to the membrane for safety reasons which might rupture, in case of faulty operation, on the effect of about 1 atm differential overpressure thus relieving the membrane. By making use of the cocks illustrated in Fig. 4, operational start-up process consisted of first gradually connecting both membrane sides to the air side of the pressure tank then, closing the connection of the two membrane sides and simultaneously opening the water side cock, connecting the membrane water side to the water side measurement point. Although operating the transmitter head according to the above specifications took quite some time and required much care, this solution proved entirely satisfactory.

Ring valve stem movement and position was directly transferred to the registration loop by means of a potentiometer type voltage transmitter fashioned to record mechanical positions.

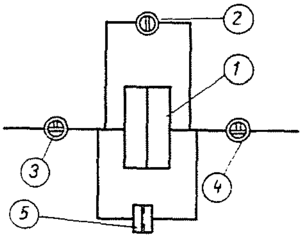

Fig. 4

The pressure gauge measurement bridge was similarly in-plant produced with dimensions of 25.5 × 19.5 × 9 cm and a weight, including batteries, of 3.1 kg. The photograph of its transistorized construction is illustrated by *Fig. 5*. Its stable indication method necessitated a stabilized ambient temperature.

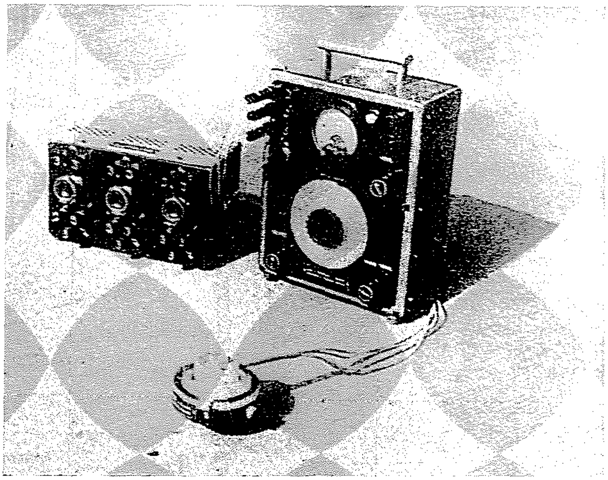

Fig. 5

The modulated 2000 cps signals received from the measurement points were made suitable for loop operation by means of either our alternating current triple amplifier shown in Fig. 5, or the similarly triple-type direct current amplifier illustrated in *Fig. 6*. It will be noted, however, that the direct output of the bridge is also suitable, with a matching transformer inserted, to operate a 1.5 mA loop therefore permitting registration in places without an electric system.

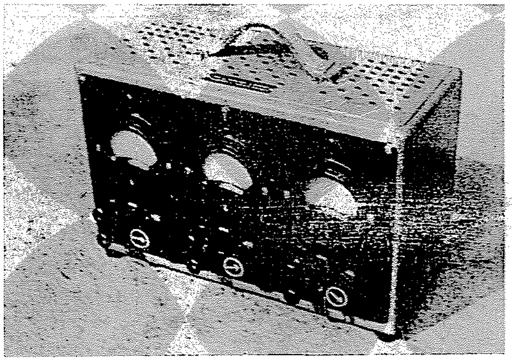

Fig. 6

V. Measurement experiences

The measurement results rendered by Plant **I** are evaluated in detail in report [2] while those obtained through Plant **II** are found in the report [3].

Here some experiences considered to deserve general interest will be presented.

With Plant **I**, as referred to above, start and stop measurements have been made by using the low-delivery pump without pressure tank in order to determine wave velocity. Thus, a very clear oscillation pattern easy to evaluate will be made available to facilitate the determination of wave propagation time.

In evaluating measurement data, *Table I* shows remarkable observations on the wave propagation time. Propagation time data were taken into account as representing the average value of several measurements. Thus in propagation time and, consequently, wave velocity a difference of about 2.2 per cent was observed.

As referred to within the description of the measuring equipment, this difference could not have been caused by the time signal.

Since quite a number of characteristics had to be registered in course of the measurements, determination of the temperature of the water delivered was completely forgotten, and the Danube water temperature values for the measurement days, in addition, had therefore to be requested from the Hydrographic Institute.

The 3-day measurement values for August amounted to 20.9, 21.1, and 21.0° C, respectively, with an average of 21.0° C whereas in November to 3.8, 3.7, and 3.6° C, showing a 3.7° C average.

Table I

Phenomenon	Cycle time, each, M—A—M	
	August	November
Start	108.5 sec	111.0 sec
Stop	109.0 sec	111.4 sec

With the calculations performed by using the characteristic pipeline dimensions, γ_v and $\tau = 4$ and 20° C, and $E_v = 2.08 \cdot 10^8$ kg/m^2 (4° C), and $E_v = 2.23 \cdot 10^8$ kg/m^2 (20° C)

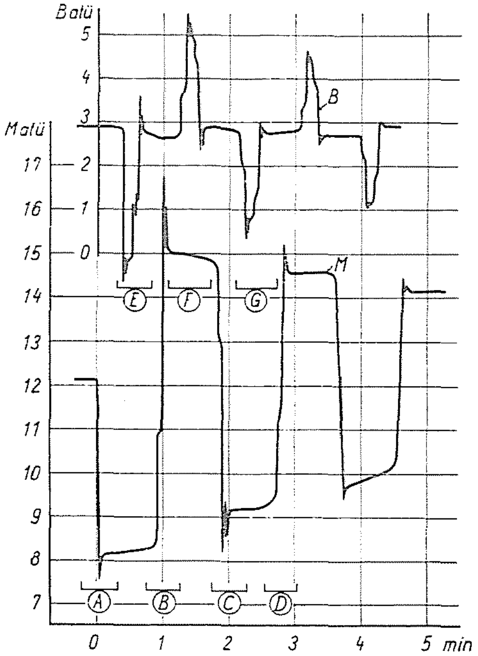

Fig. 7

pertaining to the temperature values referred to above, propagation time figures satisfactorily corresponding to the measurement values will be obtained, and the winter/summer velocity ratio will exhibit a similar agreement with the measurement results.

Testing Plant I as an inelastic system resulted in a water column interruption between points **B** and **A** in case of a sudden stop even under excessively choked operational conditions. Such a replotted registration is shown by *Fig. 7*. On the other hand, *Figs 8—10* show the photographs of details *A*, *B*, and *C*, respectively, of the pressure variation process in point **M**.

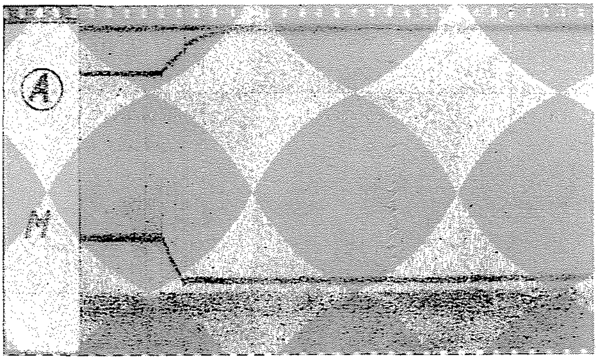

Fig. 8

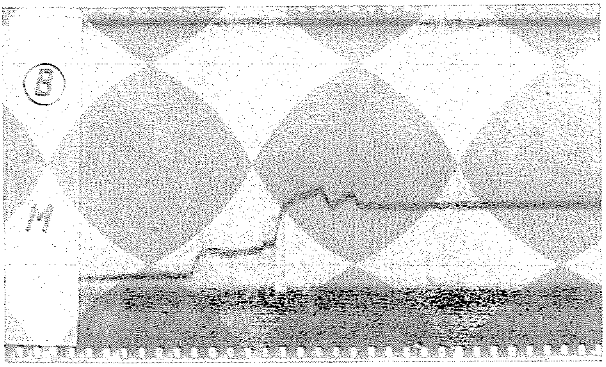

Fig. 9

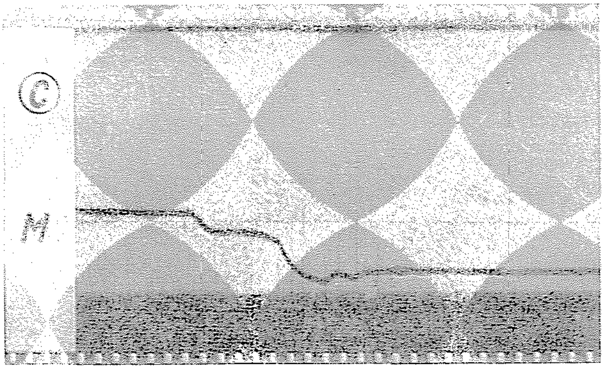

Fig. 10

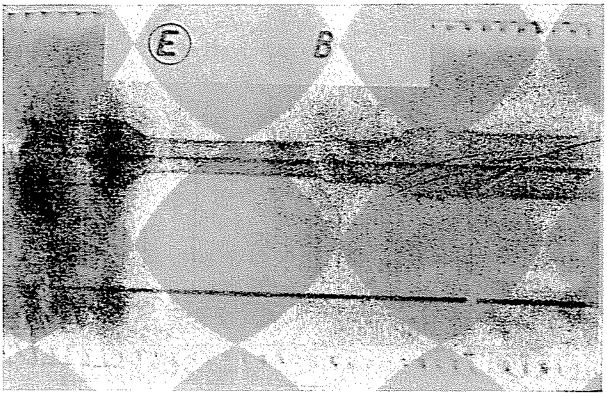

Fig. 11

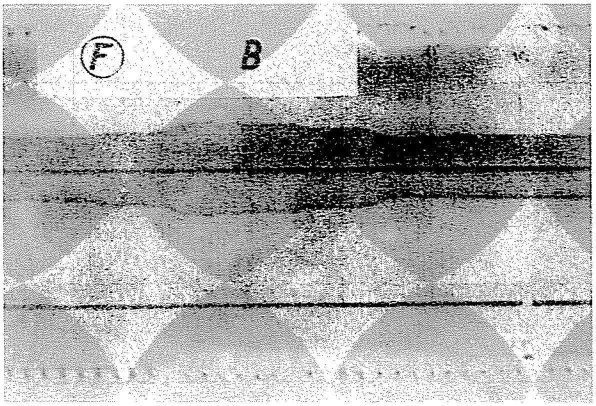

Fig. 12

Figs 11 and *12* represent the photos of details *E* and *F*, of the oscillogram obtained in point **B**.

The oscillogram obtained in case of the sudden stop of the $Q = 500$ lit/sec pump operated with 3 pressure tanks is shown in *Fig. 13*. This Figure convincigly reveals that, in point **B**, the absence of water column interruption may only be attributed to the compensation of pressure drop by the pressure rise of the wave reflected from point **A** within 21 sec. Similarly, the Figure shows that were point **A** in a distance of even only twice as much to point **B** as is at present, a water column interruption due to the later arrival of the reflected wave should be reckoned with in spite of the three pressure tanks employed.

The *N3*-type 8-loop oscillograph was first employed in the layout of Plant **II.** One of the records is presented as an example in *Fig. 14*. This Figure presents the case when the $Q = 250$ lit/sec pump operated with 3 pressure tanks suddenly fails. The closing time of the ring lock amounts to $t_z = 3.64$ sec. This oscillogram detail clearly shows that, with such a lock adjustment, the pump almost arrives at the operational speed value in course of its reversal.

Two of our measurement observations seem to deserve general attention:

One of the tasks was to study, under various operational conditions, the action of the back-pressure valve equipped with a by-pass line and inserted, next to the engine compartment, to the main pressure line. Test results may be more simply summarized in a tabulated form *(Table II)*. Comparing line

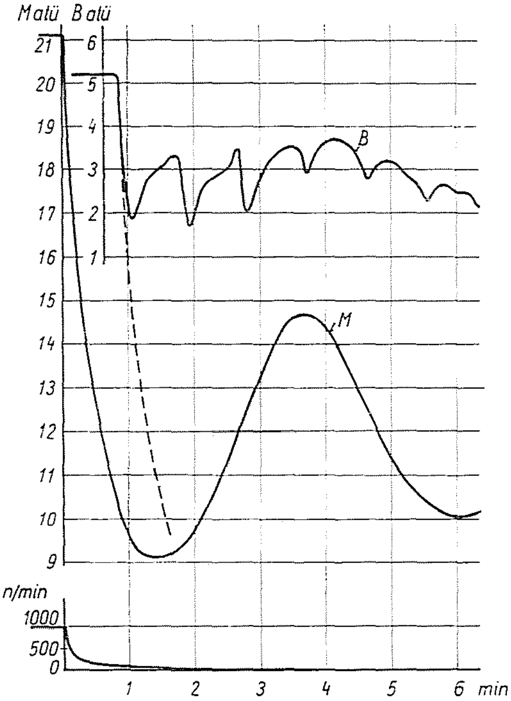

Fig. 13

Table II

No	Pump	Number of pressure tanks	By-pass	$p_{3ü}$	$p_3$min	$p_3$max
1	$Q = 440$ lit/sec	3	Opened	19	8.20	12.50
2	$Q = 440$ lit/sec	3	Closed	19	8.00	13.50
3	$Q = 440$ lit/sec	2	Opened	18.85	7.15	13.25
4	$Q = 250$ lit/sec	3	Opened	13.95	8.85	12.20
5	$Q = 250$ lit/sec	0, highly choked	Closed	13.10	5.10	19.50

1 and 2 reveals that the exclusion of the pressure tank from the return cycle does not cause an excessive pressure rise surplus, that is, the maximum of the pressure fluctuation generated does not exceed the operational pressure value. However, data in the 5th line show that the pressure maximum of the small-size pump operated with a highly reduced water quantity and without pressure tanks would first drop from the operational 13.1 atm overpressure to 5.1 but then rises to 19.5, thus, dangerously exceeding the operational value.

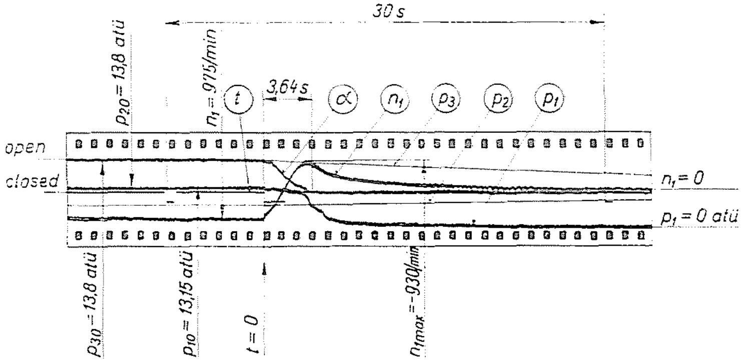

Fig. 14

The other observation concerns the back-pressure valve located in point **MP** to prevent reservoir discharge.

All sudden stop studies made the measuring device located in point **MP** show that the stopping process is always completed with a depression depending, however, on the original operational method. This cannot be considered advantageous from pipeline aspects, thus it would appear desirable to insert an open upright between the back-pressure valve and the transmission pipeline.

The examples presented as well as the experiences collected so far verify that this measuring equipment is suitable for quantitative investigations on pressure wave process and propagation phenomena.

Summary

The paper reports on the pressure fluctuation measuring equipment developed by the Department of Hydraulic Machinery, Budapest Polytechnical University, and on the measurement experiences collected therefrom. Observations to be considered of general interest, made in course of pressure fluctuation studies performed by means of two different pumping plants, are discussed. The arguments presented verify that the thus developed measuring equipment is suitable for the accomplishment of the tasks referred to.

Literature

1. Kisbocskói, L.: Measuring equipment developed to measure pressure fluctuations in extended pipelines, and the experiences obtained therewith. (In Hungarian.) Gép, **14,** 465 (1962).
2. Department of Hydraulic Machinery, Budapest Technical University, Measurement Records No 473 (Unpublished).
3. Department of Hydraulic Machinery, Budapest Technical University, Measurement Records No 498 (Unpublished).

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