EXAMINATION OF HOT WATER DISTRICT HEATING NETWORK ON AN ELECTRIC MODEL

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I. Preface

District heating is becoming ever more widespread in our days. Not only in modern, newly built cities and districts but also in quite old towns various forms of remote heat supply are to be found. Their nature (block, group or district heating) depends on the area under centralized supply and they are being set up with increasing frequency.

District heating is regarded as one of the most advanced methods. This is supported by the following advantages:

1. In the high-capacity boilers of district heating systems fuels of inferior calorific value can be utilized at higher efficiency and with lower manpower demand, viz. a smaller need of skilled labour;
2. thermal energy is available at all times and with the required parameters;
3. the coordination of electric and — heating power stations offer various advantages;
4. the pollution of the air and also fire hazards are minimised, the aesthetical aspect of the town improves;
5. substantial savings can be made in the cost of fuel and slag transport, buildings and skilled labour.

These advantages far offset any shortcomings or disadvantages that might be caused by a greater investment, or difficulties of regulation and control.

Using hot water as a heat carrying medium — which has become predominant in space heating — regulation problems can also be substantially reduced. However, to use to the best advantage this outstanding heating medium, the careful dimensioning of the heating network from the point of view of flow dynamics and its appropriate regulation is a prerequisite. For optimum dimensioning, automatic computers can be used to advantage.

In the design work and accurate dimensioning of the system, the connection of a new consumer, one that had not been reckoned with in the original design, for the operating of hotwater network appears as a major problem.

Since such cases may occur even under planned development, the question deserves attention.

Should a new consumer appear, the entire network must be dimensioned all over again, but now for the actual heating demand. To simplify this work which would otherwise require lengthy calculations, the present paper wishes to offer a suitable method.

2. The physical criteria of modelling

The application of electrical analogy may be explained by the clarification of the physical picture.

The pressure drop along a certain section of a pipework is expressed by the following relationship known from flow dynamics:

$$\Delta p = \left(\frac{l}{d}\lambda_k + \Sigma\zeta_k\right)\frac{w^2}{2g}\gamma_k \tag{1}$$

where

- Δp denotes the pressure drop in mm w. c.
- l the pipe length in m
- d the pipe diameter in mm
- λ_k the specific friction resistance along the pipe section k
- ζ_k the impact resistance (node, valve, etc.) in section k
- w the flow velocity in m/sec
- γ_k the specific gravity of the flow media along the k section, in kg/cu.m.

The above relationship may be simplified.

Let us introduce the expression V fluid flow per sec (in cu.m. per sec):

$$V = w\frac{d^2\pi}{4} \tag{2}$$

whence

$$w = \frac{4V}{d^2\pi}.$$

Substituting this into (1) we arrive at:

$$\Delta p = \left(\frac{l}{d}\lambda_k + \Sigma\zeta_k\right)\frac{16\gamma_k}{2gd^4\pi^2}V^2 . \tag{3}$$

The coefficient of V^2 on the right-hand side of the equation which contains the geometric dimensions of the network only, and is thus constant for a given flow section, may be expressed by Z_k:

$$Z_k = \left(\frac{l}{d}\lambda_k + \Sigma\zeta_k\right)\frac{16}{2gd^4\pi^2}\gamma_k \,. \tag{4}$$

After substitution, equation (1) will assume the following form:

$$\Delta p = Z_k V^2 \tag{5}$$

which latter form resembles Ohm's law as known from electricity:

$$\Delta u = Ri \tag{6}$$

where Δu denotes the voltage drop at R resistance with the current i flowing through it.

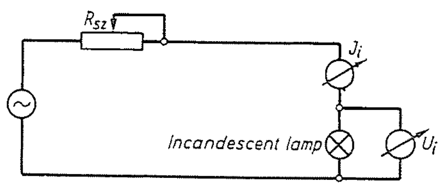

Fig. 1

As the correlation between the electric quantities is linear and fluid flow is expressed by a quadratic function, the analogy may seem somewhat arbitrary at first sight, and other possibilities for a closer analogy must be sought for.

The correlations given so far were derived mainly from mathematical-formal conversion. The physical pattern is as follows:

In fluid flow, the volume of the flowing medium is not directly proportional with the increasing pressure because at higher pressures the flow resistance in the pipe will also rise. Thus, according to relationship (5), less fluid will flow along the line than would in linear conditions.

Seeking an electric analogy for this physical phenomenon, the following will claim one's attention:

Such elements exist in electric networks in which the voltage drop is proportional to the square, or even higher powers of the current passing through them. Such an element is, for example, the metal filament lamp.

The correctness of this statement is proved by the following compilation of measurement findings (Fig. 1.):

Changing the current (I_i) passing through the incandescent lamp by means of an inserted variable resistance (R_{sz}) we measured the voltage drop on the lamp (U_i). The measurement gave the correlation according to Fig. 2.

The curve is a fair approximation of the quadratic correlation. This will at once appear from the quadratic parabola plotted close to it.

The equation of the parabola was derived as

$$U = 0.58 \cdot I^2.$$

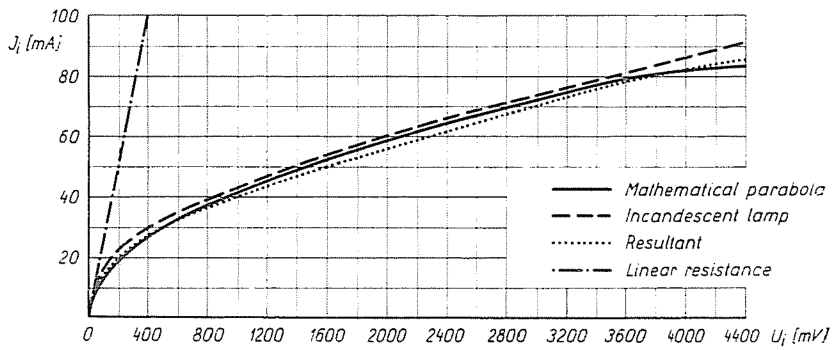

Fig. 2

The physical explanation underlaying the correlation is that the resistance of the filament also changes in proportion with the current passing through it, and with the temperature.

3. The building of the model

The model can be constructed in the following way:

The pipework is divided into sections. The Z values characteristic of each section (each Z having its separate index depending on the number of sections) can be computed on the basis of the relationships 1 through 4. (According to this division Z_k, for instance, will be characteristic of the "k" section.)

From the incandescent lamp characteristics, Z may be easily determined, since the equation of the parabola is

$$u = ZI^2. \tag{7}$$

However, a suitable incandescent lamp cannot be found for all Z_k values. According to the measurements, a 2.5 V 60 mA scale lamp with a Z value at 0.58 is a good approximation of the parabola. The required Z_k value may be attained by connecting parallelly or in series several lamps according to the needs.

A shortcoming of this method is that a more complicated network would require a relatively large number of lamps to closely approximate the Z_k value.

The question arises with what other elements of the electric mains could a good approximation of the district heating network be achieved?

More expensive, but more accurately adjustable and controllable elements are electron tubes and vacuum-tube networks.

In the normal vacuum tube amplifier the output signal is directly proportional with the input signal. This is the fundamental criterion that all distortion-free amplifiers have to satisfy.

There are electron tubes to which this criterion does not apply which, on the contrary, have a lower amplification with higher than with lower input signals. These are known as variable transconductance vacuum tubes.

A still more expensive solution, but also more efficient, is to provide each mains element with one feedback amplifier. With quadrupoles positioned in the feedback loop of the amplifiers, optional amplification characteristics can be ensured.

Our first experiments were based on incandescent-lamp models which permit good facilities for demonstration.

4. The building of the experimental model

a) *Structure and thermal calculation of the heating pipework*

To evolve an electric model which permits good analogy, we must start out from a district heating network. A system assumed to have parameters in general use is shown in Fig. 3.

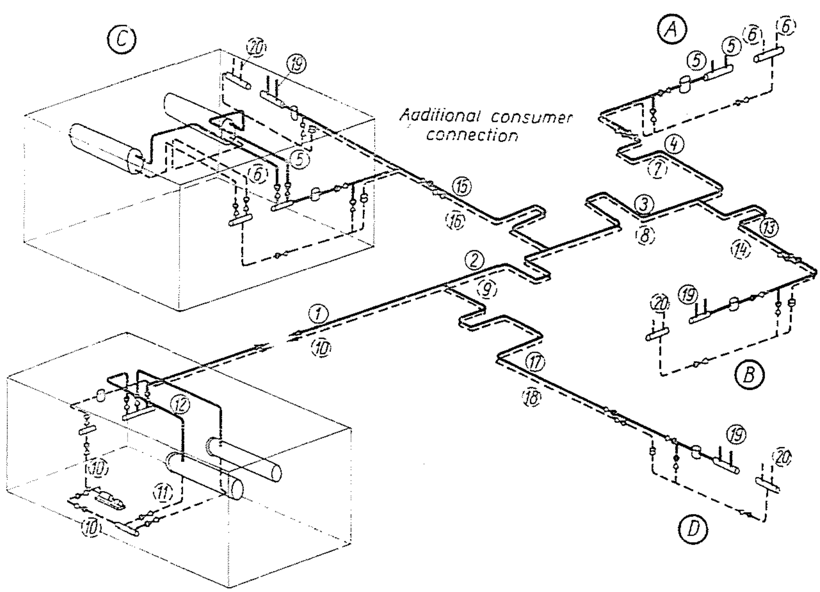

Fig. 3

This system consists of a heat producing centre, producer's and consumers' centres and pipelines. Hot water is produced in heat exchangers at the producer's centre and circulated by pumps.

Four consumers' centres are connected to the pipework, each being of the *C* design. The routing of the mains is also adapted to the practical design. (This has no importance in electric modeling since pressure loss due to form resistance may be expressed by equivalent pipe lengths.)

Hot water in the consumers' centres projects its heat to the local heat carrying medium through heat exchangers. The cooling down of the heat carrier in the mains has not been considered in the calculations.

The temperature of the forward moving water stream was taken at 130°C, the returning water at 70°C temperature. The heat quantities taken up through the two heat exchangers in the house centres are as follows:

500,000 kcal/h in centres "A" and "C"
400,000 kcal/h in centres "B" and "D"

The thermal load of each pipe section has also been derived from the above data.

For dimensioning the pipework the following method was used, the diameters of the pipe sections were determined and the requisite pump pressure calculated. Table I. is a compilation of the results of the calculations and the data relating to the pipe sections. For these latter the same signs and notations were used as in Fig. 3 and Table I.

The *G* water quantity flowing in each section (in kgs/h) was established on the basis of the following relationship:

$$G = \frac{Q}{i_{130} - i_{70}} = \frac{Q}{130.4 - 70.0} = \frac{Q}{60.4} \text{ kg/h} \tag{8}$$

where

Q denotes the heat delivered by the pipe section, in kcal/h
i the enthalpy of the water in kcal/kg

viz., transposed to litres per second:

$$V = \frac{G}{3600 \cdot \gamma} \text{ cu. dm/sec} \tag{9}$$

where

$$\gamma_{130} = 0.935 \text{ kgs/cu. dm}$$
$$\gamma_{70} = 0.978 \text{ kgs/cu. dm}$$

were calculated.

The velocity of the water flow was derived from the relationship:

$$w = \frac{V}{10\, F_p} \text{ m/sec} \tag{10}$$

where F_p denotes the territory of transverse section of pipe.

Frictional resistance in each section was calculated with the relationship:

$$\Delta p_s = \lambda \frac{L}{d_b} \frac{w^2}{2g} \gamma \text{ mm w.c.; kg/sq. m} \tag{11}$$

and the λ specific frictional coefficient was considered as the function of the pipe diameter and water temperature.

The form resistance was determined in each section on the basis of the following relationship:

$$\Delta p_a = \Sigma \zeta \frac{w^2}{2g} \gamma \quad \text{mm w.c.; kg/sq.m.} \tag{12}$$

The actual values have been tabulated in Table I.

In determining the coefficient of the form resistance in the confluence resp. division of streams, the quantitative relations have also been taken into consideration.

The pressure utilisable in the auxiliary circuits were calculated on the consideration, that from each point of bifurcation, identical pressure must be consumed in all directions. Thus, the same pressure that is used up along the sections 3—4—5—6—7 and 8, must be consumed at the same rated flow also in sections 15—5—6—16. Pressure loss in all auxiliary circuits is lower than the available rate, the balance is to be used up by a throttle valve.

b) *Electric analogy and model*

The values of Z_k are calculable on the basis of equation (5). With the unit system applied in the work, it seemed expedient to divide the Z_k values by ten and round them up or off into integers. These will then determine the number of lamps required along the section under examination.

In building up the network we started out on the principle that each lamp is used as a Z "unit", that is, as many lamps must be inserted as will be enough to make Z the highest common divisor in the various sections at Z_k value.

Since this cannot be accomplished except by approximation, thus we must determine in advance what degree of error is permissible. The table clearly shows that with the above number of lamps the greatest errors (around 7 per cent) may be expected along the second section.

Table I.

1	2	3	4	5	6	7	8	9
Number of section	Q kcal/h	t °C	d_k/d_b mm	d_b m	L m	G kg/h	V dm³/sec	F_p dm²
	Effective circuit							
1	1 800 000	130	108/100	0.1005	650	29 800	8.85	0.793
2	1 400 000	130	102/94	0.0945	100	23 180	6.89	0.707
3	900 000	130	89/82	0.0825	200	14 900	4.43	0.535
4	500 000	130	76/70	0.0700	150	8 280	2.46	0.385
5	250 000	130	57/51	0.0515	10	4 140	1.23	0.208
6	250 000	70	57/51	0.0515	10	4 140	1.18	0.208
7	500 000	70	76/70	0.0700	155	8 280	2.35	0.385
8	900 000	70	89/82	0.0825	200	14 900	4.23	0.535
9	1 400 000	70	102/94	0.0945	100	23 180	6.58	0.707
10	1 800 000	70	108/100	0.1005	660	29 800	8.46	0.793
11	900 000	70	89/82	0.0825	5	14 900	4.23	0.535
12	900 000	130	89/82	0.0825	10	14 900	4.43	0.535
	Auxiliary circuits				"B"	circuit.	Applicable	
13	400 000	130	70/64	0.0640	80	6 620	1.97	0.322
19	200 000	130	57/51	0.0515	10	3 310	0.98	0.208
20	200 000	70	57/51	0.0515	10	3 310	0.94	0.208
14	400 000	70	70/64	0.0640	85	6 620	1.88	0.322
					"C"	circuit.	Applicable	
15	500 000	130	70/64	0.0640	120	8 280	2.46	0.322
5	250 000	130	57/51	0.0515	10	4 140	1.23	0.208
6	250 000	70	57/51	0.0515	10	4 140	1.18	0.208
16	500 000	70	70/64	0.0640	125	8 280	2.35	0.322
					"D"	circuit.	Applicable	
17	400 000	130	57/51	0.0515	140	6 620	1.97	0.208
19	200 000	130	57/51	0.0515	10	3 310	0.98	0.208
20	200 000	70	57/51	0.0515	10	3 310	0.94	0.208
18	400 000	70	57/51	0.0515	145	6 620	1.88	0.208
	Additional circuit.							
19	200 000	130	57/51	0.0515	10	3 310	0.98	0.208
20	200 000	70	57/51	0.0515	10	3 310	0.94	0.208

10	11	12	13	14	15	16	17	18	19
v m/sec	λ	Δp_s mm w.c.	$\Sigma\zeta$	Δp_a mm w.c.	$\Delta p = \Delta p_s + \Delta p_a$ mm w.c.	$\Sigma \Delta p$ mm w.c.	V^2	$Z_k = \frac{\Delta p}{V^2}$	n piece
1.12	0.016	6 184	13.6	813	6 997	6 997	78.0	89.5	9
0.97	0.016	759	2.6	117	876	7 873	47.5	18.5	2
0.83	0.016	1 274	2.7	89	1 363	9 236	19.6	70.0	7
0.64	0.017	712	16.1	315	1 027	10 263	6.05	170.0	17
0.59	0.017	55	7.3	121	176	10 439	1.51	116.0	12
0.57	0.019	60	7.3	118	178	10 617	1.39	128.0	13
0.61	0.019	780	8.6	159	939	11 556	5.5	170.0	17
0.79	0.018	1 358	2.9	90	1 448	13 004	18.0	80.0	8
0.93	0.017	776	2.3	121	897	13 901	43.4	20.7	2
1.07	0.017	6 373	36.6	2 089	8 462	22 363	72.0	117.0	12
0.79	0.018	34	5.2	162	196	22 559	18.0		
0.83	0.016	64	6.6	217	281	22 840	19.6		
2320 mm w.c.									
0.61	0.017	377	16.1	285	662	662	3.86	170.0	17
0.47	0.018	37	7.3	77	114	776	0.96	120.0	12
0.45	0.019	37	7.3	74	111	887	0.88	126.0	13
0.58	0.019	423	8.6	144	567	1 454	3.5	165.0	17
5131 mm w.c.									
0.76	0.017	878	16.1	444	1 322	1 322	6.0	220.0	22
0.59	0.018	55	7.3	121	176	1 498	1.51	116.0	12
0.57	0.019	60	7.3	118	178	1 676	1.39	128.0	13
0.73	0.019	986	8.6	229	1 215	2 891	5.5	222.0	22
6904 mm w.c.									
0.95	0.017	1 989	16.1	693	2 682	2 682	3.86	697.0	70
0.47	0.018	37	7.3	77	114	2 796	0.96	120.0	12
0.45	0.019	37	7.3	74	111	2 907	0.88	126.0	13
0.90	0.019	2 160	8.6	347	2 507	5 414	3.5	714.0	71

0.47	0.018	37	7.3	77	114	114	0.96	117	12
0.45	0.019	37	7.3	74	111	225	0.88	125	13

Examining more thoroughly the curve characteristic of the incandescent lamps, it can be seen that its initial section is linear (the cold lamp acts as Ohmic resistance). This will, in the neighbourhood of 200 mV cause a considerable deviation from the mathematical parabola. The degree of error can be minimised by connecting in series an ohmic resistance of linear characteristics with the non-linear lamp. Plotting the straight line of the resistance and performing graphic summation because of the series-connection, we arrive at the resultant curve seen in Fig. 2.

This curve in the initial section fairly covers the quadratic parabola and the divergence at higher values, in terms of relative error, will be substantially smaller than in the initial section without the resistors.

Accuracy may further be increased in such a way that when the network is complete, the magnitude of the current flowing in the examined section is established in the very first measurements. If the current is below 30 mA, the insertion of a linearizing member of a value of $200/50 = 4\,\Omega$ per lamp (see the figure) is advantageous. With currents above 30 mA, the linearising resistance may be dispensed with, the more so as the quadratic characteristics are more closely approximated in this way.

c) *The practical build-up of the model*

The network has been built up from the number of lamps as computed in the Table. It should be noted at this point that the soldering of bonds is indispensable because in threaded contacts (sockles etc.) even the smallest measure of loosening would bring about contact resistances of a magnitude comparable to the resistance of the lamp and so affect measurement accuracy. Soldering on the model is easy to perform for the lamp outlets are also soldered.

The model of the network was built up on a large-size board (1.5×2.0 m) (Fig. 4.) spread in plane. Substituting the throttling values with equivalent pipe lenghts, the requisite number of lamps could be determined. Each throttle constitutes a small separate unit.

Linearizing resistances were inserted into the loops where current value was below 30 mA and the network was fixed by pins to the board at 10 to 20 centimetres apart. The 11th and 12th sections were substituted by the internal resistance of the electric generator (the pump in the heating network).

The current source which was to serve as an analogy for the pump pressure was evolved in the following manner:

According to preliminary calculations about 100 to 130 Volts are needed to perform measurements on the network, because at such voltage rate the load on the lamps in the main loop will be at its maximum. It is important to attain maximum load in the main loop for it is only in this way that the small voltage drops in the side loops are measurable. We shall revert to this problem later.

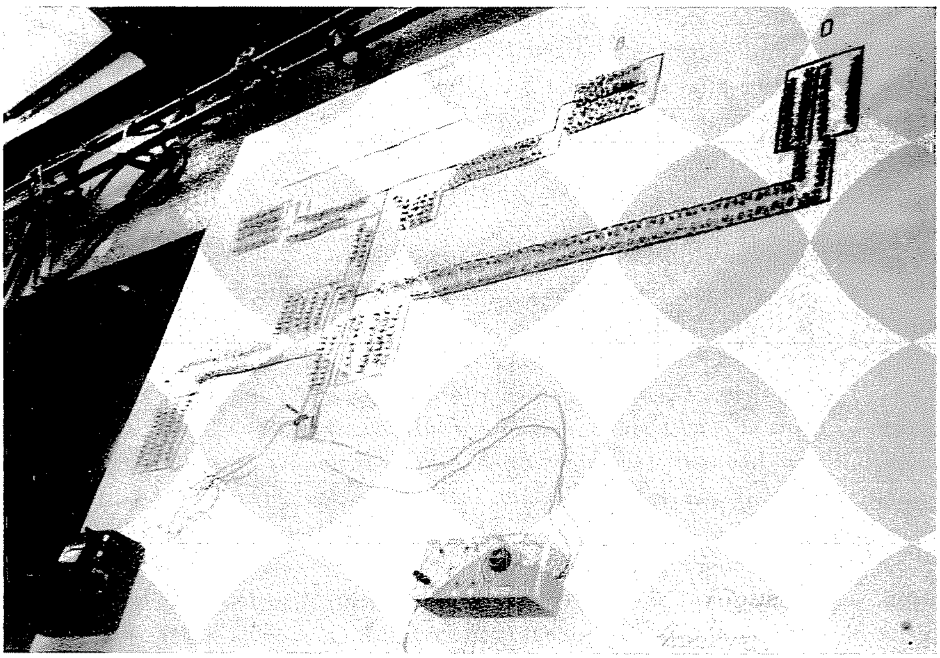

Fig. 4

To utilise the available 220 Volt mains voltage, variable series-resistors must be inserted into the circuit (Fig. 5) of a size not larger than is necessary to supply one single lamp. At 220 V 60 mA (the 2.5 V being negligible) the rated current required for the lamp is

$$R = \frac{220\,\mathrm{V}}{0.06\,\mathrm{A}} = 3700\,\Omega.$$

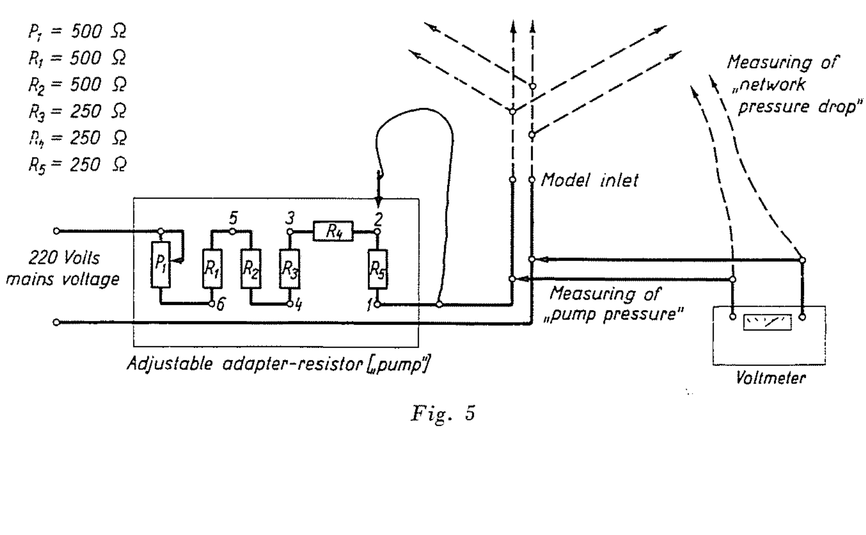

Fig. 5

To meet the case, it is advisable to provide an adapter of 4000 Ω in 500 Ω steps and complement it with one 500 Ω potentiometer.

In practice all values from 0 to 4000 Ω can be adjusted. The loadability of the resistors and the potentiometer shall be

$$P = i^2 \cdot R = 0.06^2 \cdot 500 = 1.8 \cong 2 \text{ W}.$$

Resistors and potentiometer were built into a box. From the two pairs of wires leading to the box one is connected to the mains voltage and the other supplies the model (Fig. 5).

This solution is simple but has a snag, in that the touching of the network (lamps) is dangerous and therefore prohibited. With inadequately insulated flooring, contact with even one loop would cause serious shock. Should any manipulation become necessary during measurements (re-positioning of the apparatus or any other modification in the network), the whole system must be cut off.

The instrument used in the measurements was the Univeka Type 137 Urav., an outstanding means for such work, having a sufficiently large internal resistance even at the a.c. measurement limit (20,000 Ω/Volt) while at 1 V limit its internal resistance is 20 kΩ. This means that as against the around 50 Ω resistance of the lamp, this value is some 400 times higher. The apparatus will not cause greater errors in the network current. Error is 0.25 per cent, much lower than the inherent inaccuracy of the instrument (3 per cent).

The above calculation refers to measurements performed at the lowest limit (1 V) because the internal resistance of the instrument is the lowest at this point.

Due to the higher resultant resistance, the fault will increase if several lamps connected in series are being measured. Measuring the voltage on 8 to 10 lamps at the 1 V range, 2 per cent fault likely to arise in the measurement will not be overstepped. It is seldom that more than 8—10 lamps are measured at such low measuring range as the current flowing across the lamps is very small.

Current cannot be metered because this would call for the cutting off of the circuit. The current flowing in the individual loops can be determined from the voltages measured at the lamp poles in the respective loop with the aid of the plotted lamp characteristics.

Measurements were performed to establish the stability of lamp characteristics. Twenty lamps were taken at random from several packages and subjected to examination. The findings fall into the zone illustrated in Fig. 6. Their range should be considered when the currents are being determined.

Maximum errors have not been considered when building the model. With a number of lamps connected in series, errors due to scattering are partly offset. To construct a very accurate model, the value of each completed line section should be separately "adjusted" by adding or removing lamps, or by a slight change in the value of the linear resistance.

Putting the complete network into operation, the problem will arise which voltage (for the pump: what pressure) shall be connected to the network. In principle, the model can be operated off optional voltage since the quadratic characteristic of the lamp takes care — except one proportionality factor which is the dimension of the pump pressure (generator voltage) of the faultless operation of the model. This, in other words means, that at optional mains

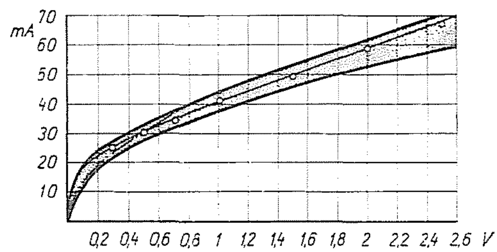

Fig. 6

voltage measured at any point, multiplied by the coefficient pump pressure per generator voltage characterising the supply point, will yield the actual pressure at a given point of the pipe system.

In practice we naturally aim at having well measurable values and for this reason at the supply point we produce a possibly high voltage in the main loop, equal to or preferably even higher than the rated lamp current. This would ensure the maximum current even in the farthest loops and, moreover, ensure that the flowing current even in the farthest loops, shows a well defined voltage drop.

5. Measurements on the model

According to what has been set out in the foregoing, at the beginning of the measurements the current is, by means of the variable resistor, adjusted to a level that permits a voltage drop of some 3.7 Volts to take place on each lamp in the main loop. Under such a degree of overvoltage, the lamps may still have a long service life. (The mains, of course, were put under current for the time of the measurements only.)

This adjustment is advantageous because supply voltage may be set to 112 V, whereby the pressure/voltage drop quotient will be an integer multiple of the 22 363 mm water gauge pressure, figuring in our calculations.

With a slight, 0.25 per cent neglection:

$$\frac{22\,400}{112} = 200 \frac{\text{w.c. mm}}{\text{Volts}}$$

The voltages measured in the loop are as follows:

112 V corresponds to			......	22,400 mm
34.5 V	— measured 32.5 V	— error 5.8%	to	6,900 mm
25.15 V	— measured 24.0 V	— error 4.6%	to	5,130 mm
11.6 V	— measured 10.4 V	— error 10.3%	to	2,320 mm

The above values can be measured in uncorrected networks, viz. where the differences between lamp characteristics were disregarded and neither could some sections over the 4 to 7 per cent error in the number of lamps be eliminated, so as to arrive at an integer number of lamps.

Measurements have largely shown that lamps having quadratic characteristics actually enable a fair approximation to be made of the conditions of fluid flow in pipeworks. This means that the assumption and object we had set out to realize, have been proved by experiments.

Now the problem is whether and in what way modelling according to the above method helps to do away with the need for recalculating the entire network, should a modification become necessary.

To an already given and fully calculated completed network a new consumer must be connected at some given point. We know the requirements that have to be met with the entry of the new consumer, viz. we know the quantity of hot water his equipment will need and the magnitude of the pressure drop his entry will cause on the new pipe section. From these two data the Z_k value characteristic of the "equivalent pipe length" can be computed.

$$Z_k = \frac{\Delta p}{V_u^2}$$

(in the form already known; the index refers to the "new" pipe section).

We have built up the electric model of the original pipework and put it into operation. Subsequently we set up the lamp network corresponding to the calculated Z_u value and have connected it to the original network at the given points.

The conditions in the original network will, of course, show substantial changes and also the new one will yield a voltage drop different from the expected value. Now, by upward correction of the generator voltage (position of the potentiometer) we produced the original voltage drop at the points of connection.

If this is feasible without the overloading of the lamps along the line up to the node (2.5 V lamps may be loaded at 4 V for short periods), the old network section supplied off the branch has again resumed operation under the previous, adequate, working conditions.

At this juncture there are two possibilities. Along the new network, voltage drop may be 1. lower or 2. higher than required. Cases in which the voltage drop is exactly as required, are few and far between. This problem may be decided on, even before the measurements have been performed, since we know the voltage drop value of the old network between the respective points and also the voltage drop likely to be caused by the new section.

Should voltage drop be smaller, additional lamps (throttles) should be connected into the section supplied off the node, and the current in the main loop further increased until the voltage demand of the new section becomes manifest at the node.

Working conditions have thereby been established in the network from the branching section onwards.

Due to the higher pressure prevailing in the main loop, the consumers connected ahead of the node point will no doubt also need additional "throttles". These must be inserted in such a manner that they will help to attain the original operating conditions over the whole network. While from the number of lamps the flow dynamics value of the throttles may be recalculated (from Z_k), the dimensions of the new pump can be calculated according to the voltage rate of the generator.

Should case 2. apply, viz. the new network be under higher voltage, the throttle shall be inserted in the network in such a manner that it receives the necessary voltage. Recomputation and pump correction must be similar to case 1.

Should the pressure drop by some accident on the new section be equal to pressure/voltage drop on the old one, then only the section up to the node shall be corrected, due to increased generator voltage.

For the sake of completeness we wish to mention that the here described method is expedient only if the new consumer does not exert excessive load on the old network. In other words, if the old pipework with a larger pump and a few new throttles is capable of supplying the new consumers. This, for the electric model will manifest itself in such a way that the lamps in the main loop will not stand an overload beyond the above mentioned cca 4 V and voltage (pump pressure) cannot be augmented at will.

Should the new network be loaded to such an extent that normal working conditions cannot be restored by merely increasing the pump pressure, then new larger-diameter pipework would have to be installed. Without exception the electric model will give a clearly visible danger signal by brightly flashing lamps due to excessive voltage.

To give an example for the application of this method in practice, we have added a new consumer to the district heating network. Its particulars are shown in Table I.

The new consumer was inserted immediately adjacent to C and connected to its service line. A voltage drop was felt at all points of the network. Now the "pump" voltage was increased so as to restore the original level in the node of the 15th and 16th sections. When it became evident that *C* did not get the current supply it required the number of lamps (throttles) had to be decreased — carefully so as to maintain voltage in the 15th and 16th node points.

It was found that the C needs no throttling but the new consumer requires 17 lamps — given which both C and the new consumer obtain the supply they need.

Since, due to higher pump pressure, an overconsumption became manifest at the 17th—18th point, the original level had to be restored at the node point only. This was carried out by the insertion of 16 lamps, viz. throttling was increased.

Ultimately, equilibrium state was restored with the following values:

	New V	Old V	New mm w.c.	Old mm w.c.
Pump pressure	136	112	27 200	22 363
17—18 points	35	32	7 470	6 904
15—16 points	24	24	5 131	5 131

The 17 "throttling lamps" of the new consumer, according to

$$\Delta p = V^2 \cdot Z_k$$

correspond to a throttling of 148 mm w.c. while C can be connected without throttling whatsoever.

In the 17—18 loop, 16 lamps correspond to 566 mm w.c. higher throttling value.

Finally, it is evident that pump pressure must be increased by 4837 mm w.c.

Summary

The paper deals with the electric model of hot water district heating. Above all it carefully studies the pressure conditions in the network. In addition to the physical criteria of modelling the paper demonstrates the build-up of the electric model of a district heating giving the measurements in it.

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