DETERMINATION OF THE IMPACT ENERGY OF THE NEK-8 TYPE HERF MACHINE

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I. Introduction and objectives

The most important technological characteristics of the machines, hammers, presses, etc., forming by impact or compression in the technological practice of plastic formation is the energy available for single-run forming.

Determination of the energy available for the process of formation may be by direct or indirect methods. The simplest direct method was suggested by WATERMANN [1], and employed for the measurement of the forming energy of hammers, crank and friction presses. Essentially, the method consists of deforming by compaction the samples made of electrolytic copper of known strength properties with the machine to be tested, then concluding from the deformation of the specimen to the forming energy. This method is adaptable, of course, only within such deformation or deformation rate ranges wherein the yield curve of the copper is known.

In the case of high-speed forming machines, the rate of impact is generally $u = 10$ to 30 m/sec. The Watermann method can be used, authentically, up to a maximum deformation rate of $c = 300$ sec^{-1}. Accordingly, the test requires compaction samples of a minimum height of $h = u/c = 30/300 = 0.1$ m^{-1}. This 100 mm is comparable to the 200 $\sim$ 600 mm stroke of the impact test machines described in literature, and is about one-third of the 300 mm stroke of the NEK-8 machine. The motion equations of NEK-8 reveal [2], that, during an impact on such high samples, the energy carrier N_2 gas can expand only to about the two-third of the full stroke and, consequently, the maximum forming energy cannot be measured.

On the basis of the above considerations, determination of the impact energy of NEK-8 had to employ an indirect method. This means measurement of the velocity of movement of the moving parts in the machine, during the impact process, since the impact energy can be calculated therefrom.

Such indirect measurements were performed by KAWADA, SUZUKI and others [3], with a Type Dynapak-1220 high-speed forging machine, by measuring the displacement of the ram by means of an ohmic relay as a function of time. Derivation of the function thus obtained permits the calculation of the velocity and, therefrom, the motion energy of the ram. Suzuki and his associates operated within a relatively narrow speed range. Their method, however, could not be used because the reliable operation of the resistance pitch moving contact could not even be estimated at the expected extreme accelerations.

ORGAN [4] used, in addition to the Watermann test, an inductive rate relay for the calibration of the high-speed forging machine Petro—Forge of a high stroke number per min, short stroke, relatively small energy, etc. The ram velocity of the high-speed hammer 16 Mpm developed in the Soviet Union was measured by SALOV and BOTCHEROV [5] by the impulses of the small-size inductive relays located along the accelerating stroke section. This method is, however, not accurate enough for the measurement of the impact rate as it will not render a continuous shift function but only some points and, generally, the impact point will not coincide with any of the relays. Following the impact, velocity measurement is by a capacitive path marker; in the 5 to 10 m/sec range, a photoelectronic equipment with a C-60 M symbol is also used.

High-speed film may be similarly suitable for impact rate and energy measurements. This method was employed by the Research Film Department of the Instrumentation Service of the Hungarian Academy of Sciences, by means of the 600 mkp and 8 Mpm experimental machines of the Research Institute for Metal Industry [6]. With the film speed applied, the displacement/time curve obtained by high-speed shooting could not be evaluated properly, and the method was too expensive, anyway.

A common characteristic of the indirect methods outlined above is that they measure, somehow or other, the entire ram displacement or part thereof as a function of time, although the impact energy of the ram is governed by the velocity of the moving parts in the moment of impact. Every displacement (rate)-time curve will necessarily require some compromise: the velocity condition prior to and at the instant of impact will differ by orders of magnitude if compared, which needs the extension of the range of registration and leads, thereby, to a considerable reduction in measurement accuracy.

This is why such a measurement method had to be developed whereby, at the instant of impact, the velocity could be measured without the use of any instrument designed specially for this purpose wherefrom, then, the impact energy could be calculated. The final impact speed is the only essential parameter, whereas plotting the complete path/time or rate/time function is insignificant with respect to forming.

II. Measurement principle

The operation of the ram to be tested has been analyzed in detail by [2]. The model simplified with respect to the velocity conditions is presented in Fig. 1.

According to the model symbols, the expansion started in cylinder A will simultaneously accelerate ram m and frame M. Expressing the impulse theorem for any time t, we get

$$v_m = v_M \frac{M}{m} \tag{1}$$

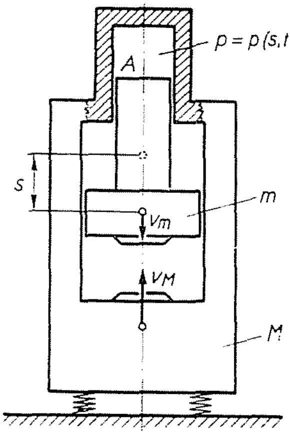

Fig. 1

independently of the momentary value of v_m and v_M, respectively. At the instant of impact let us have $v_m = V_m$, and $v_M = V_M$. The acceleration of high-speed rams is much greater than free drop. The ram moving downward may carry along or rather push a small-size body b whose speed will be identical to its own. This speed identity will exist up to the instant of impact.

At the instant of impact, the ram speed will necessarily change to a significant extent, whereas the velocity of the body b moving simultaneously will maintain the speed condition at the instant of impact.

Let us place a free moving body of ΔH symbol distance onto the anvil (frame). This, too, will move along with the machine at a rate v_M, which will not change at the instant of impact, either.

The instant of impact is illustrated in Fig. 2a. Be the mass of body b equal to b, and that of the measuring head a equal to a. The velocity variation of masses a and b after the impact will be caused exclusively by acceleration due to gravity. If we indicate the velocity of body b by V_b, and that of the measuring head by V_a, we get

$$b \frac{dV_b}{dt} = bg \tag{2a}$$

$$a \frac{dV_a}{dt} = -ag. \tag{2b}$$

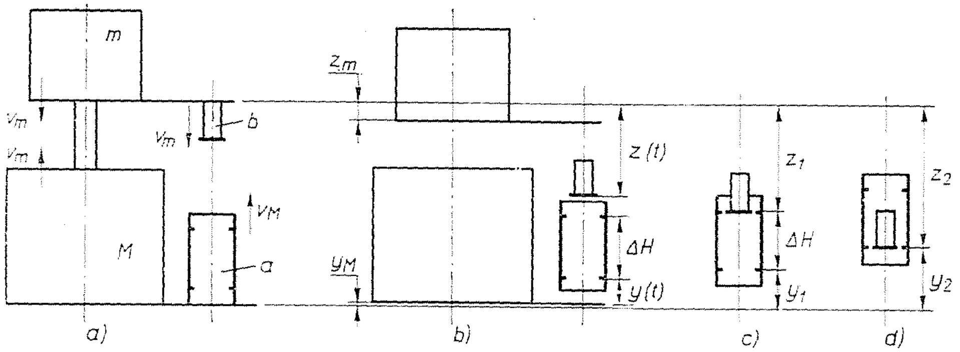

Fig. 2

At the instant of impact, if $t = 0$, $V_b = V_m$ and $V_a = V_M$, we obtain

$$V_b = V_m + gt \tag{3a}$$

and

$$V_a = V_M - gt \tag{3b}$$

Now let us have

$$k = \frac{m}{M}$$

whereby from (1), instead of (3b), we may write

$$V_a = kV_m - gt \tag{4}$$

At an optional instant t after impact, the relative positions of ram, frame, body b, and measuring head are illustrated in Fig. 2b. The patch covered by body b during a period t, as from Eq. (3a), since

$$V_b = \frac{dz}{dt}$$

will be

$$z = V_m t + g\frac{t^2}{2} + C_1 \tag{5a}$$

whereas the path covered by the measuring body, from Eq. (4), will amount to

$$y = kV_m t - g\frac{t^2}{2} + C_2 \tag{5b}$$

Body b will meet the top contact of the measuring head at time t_1 when, from (5a) and (5b), we get

$$z_1 = V_m t_1 + \frac{gt_1^2}{2} + C_1 \tag{6a}$$

$$y_1 = kV_m t_1 - \frac{gt_1^2}{2} + C_1 \tag{6b}$$

With the bottom contact, body b will create connection at time t_2 when

$$z_2 = V_m t_2 + \frac{gt_2^2}{2} + C_1 \tag{7a}$$

$$y_2 = kV_m t_2 - \frac{gt_2^2}{2} + C_2. \tag{7b}$$

On the basis of Figs 2a and 2b, the following equation may be written:

$$z_1 + \Delta H + y_1 = z_2 + y_2 \tag{8}$$

Substituting equation systems (6) and (7) into (8), we get

$$V_m(1 + k)(t_2 - t_1) = \Delta H \tag{9}$$

since the relative velocity between ram and frame is

$$V_{\mathrm{rel}} = V_b + V_a \tag{10}$$

By using Eqs (3a) and (4), we obtain

$$V_{\mathrm{rel}} = V_m(1 + k) \tag{11}$$

Substituting now Eq. (11) into (9), we shall have

$$V_{\mathrm{rel}} = \frac{H}{t_2 - t_1}. \tag{12}$$

The standard impact energy of the machine is

$$E = \frac{mV_m^2}{2} + \frac{MV_M^2}{2}. \tag{13}$$

Substituting Eqs (1) and (11), we arrive at

$$E = \frac{mV_{rel}^2}{2} \cdot \frac{1}{1+k}. \tag{14}$$

According to (12), the problem can be reduced to a simple time measurement and, since velocity V_{rel} can be measured in this case, we can introduce the measurable energy definition

$$E_{\mathrm{meas}} = \frac{mV_{\mathrm{rel}}^2}{2}$$

whereby the impact energy of the machine will equal

$$E_{\mathrm{mach}} = E_{\mathrm{meas}} \frac{1}{1+k} \tag{15}$$

III. Construction of the measuring equipment

The photo of the mechanical part of the equipment is presented in Fig. 3. The machine is ready to impact. At this instant, body *b* (1) is fixed to a rigid fork (3) made of an insulating material which, in turn, is mounted to the ram by means of a small-size, similarly insulated tongs (2).

In the schematic diagram, the measuring head *a* is represented by a tube made of an insulating material (5), whereon the measurement length marked ΔH is indicated by two Λ-shaped contacts of soft tinned copper wire 0.1 mm thick. The measuring head (5) can move, as permitted by the thin wires (6) and (7), without rotation. Body *b* is a thin-wall missile shape object whereon stabilizer planes similar to those of the aircraft bomb surface have been formed. This body is guided by a steel wire to which it is connected through Teflon bearings. The measuring body is sliding on the same type of bearings. The wings of body *b* are enclosed by a copper ring which performs contact closure.

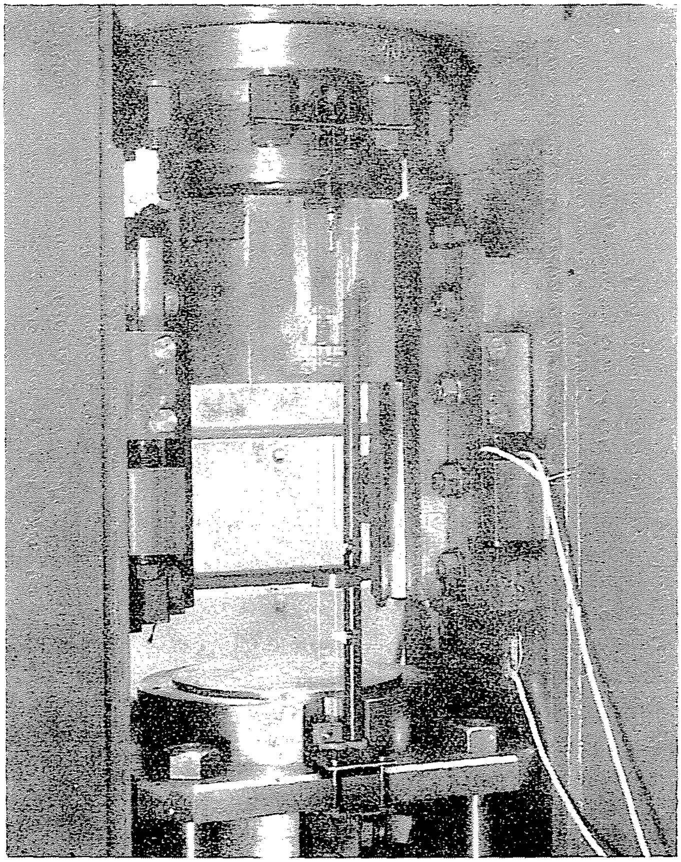

Fig. 3

The electric connection between body b and wire is by a very thin p.b. spring.

When starting the machine, the work (3) removes body b from between the tongs (2), and continues to push it as illustrated in Fig. 2a. At time t_1, when body b and the measuring head meet, the top contact will close and thereby, via a trigger, will switch on a counter which is, essentially, a quartz dial. At time t_2 the bottom contact will close and, by this impulse, the trigger will lock and the counter stop.

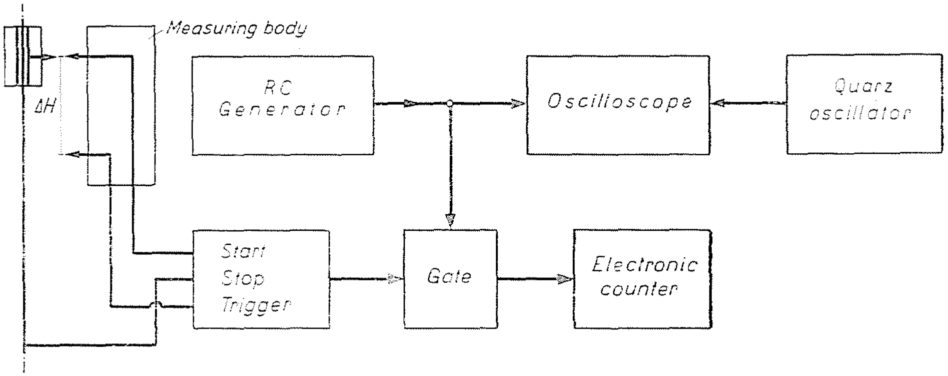

Fig. 4

The decadic counter is to count the impulses of a 200 kc.p.s. sound generator. Frequency stability is ensured by continuously comparing the reference signal produced by a quartz oscillator to the sound generator signal, by means of a Lissajous curve observed on the associated oscillo-synchroscope. The block diagram of the electronic equipment is illustrated in Fig. 4.

Calibration of the equipment was by the free drop of body b, when the time required for covering the distance $\Delta H = 100$ mm was measured and, therefrom, the acceleration due to gravity was calculated; this value differed by less than 3 per cent from the Budapest figure. Thus the equipment was considered as suitable for the purpose.

IV. Measurements

The primary objective of the measurements performed with the NEK-type machine was to verify the validity of the energy determination formula derived from the operational principle of the machine. For this purpose, the soft electrolyte copper prisms suggested by WATERMANN [1] were formed at room temperature, while the equipment described above was used to measure the time difference $t_2 - t_1$ from which the impact energy could then be determined by making use of Eqs (12) and (15). All this could be measured, however, only in the lower energy (rate) range, as only the small-size samples required here (dia 24×36, 32×48 and 40×60) could provide for a specimen length less than 20 per cent of the stroke, and satisfy the precondition $c < 300^{-1}$ sec. With higher energies ($E > 4000$ mkp), aluminium and copper specimens of different dimensions have been formed while the impact rate was measured and, on the basis of formula [2],

$$E_c = \frac{p_0 V_0}{\varkappa - 1}\left[1 - \left(1 + \frac{A_d\, x}{V_0}\right)^{1-\varkappa}\right] \qquad (16)$$

was used for calculating the impact energy, where:

p_0 = initial starting gas pressure in the pneumatic cylinder of the machine;
V_0 = charge volume of the expanding gas;
A_d = cross-section of the piston rod;
x = stroke;
$\varkappa$ = 1.4 related to the nitrogen gas employed by the machine.

According to the above relation, the energy calculated for each impact is proportional to the starting gas pressure p_0 thus the energy calculation is as accurate as precisely p_0 can be measured. On the NEK-8 machine, the starting gas pressure was measured by means of an ordinary bellows manometer.

Fig. 5 illustrates the total forming energy determined by the Watermann test, as a function of the work defined by velocity measurement. The measurement points show a correlation of $r = 0.9967$ which corresponds to a functional relation. The directional tangent

$$\tan \Theta = \frac{E_w}{E_g} \qquad (17)$$

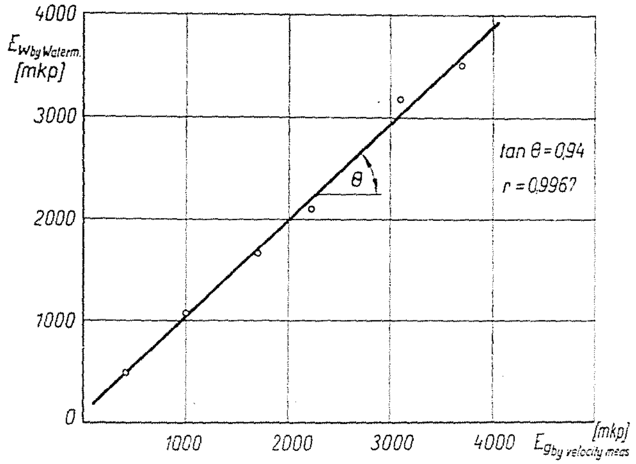

Fig. 5

renders the energy ratio used and utilized for impact, that is, the impact efficiency which, as determined by correlation calculation technique, amounts to 0.94.

Expressing the energies E_g determined by velocity measurements as a function of E_c calculated from (16), again a straight line is obtained (Fig. 6) whose equation, at a correlation of $r = 0.9933$, will be

$$E_g = 1.02\ E_c - 278 \text{ mkp} \tag{18a}$$

or

$$E_g = 1.02\ E_c - 2010 \text{ ft lb} \tag{18b}$$

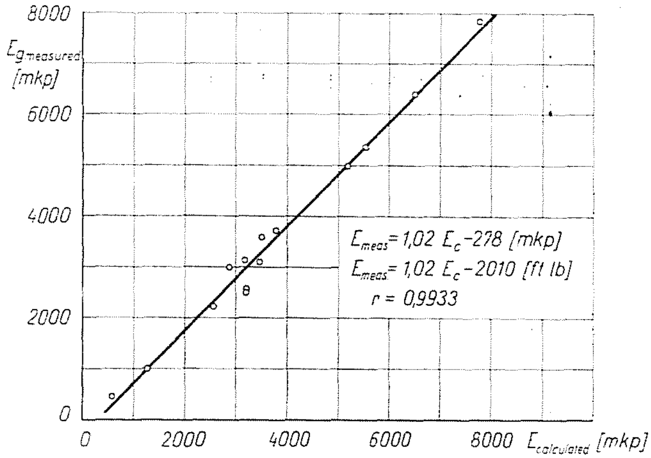

Fig. 6

It follows that $E_g = 0$, if $E = 272$ mkp. In the general case of stroke $x = 300$, this means that the machine will not operate at a pressure of about 5 kp/cm^2, or lower. Actually, this figure is due, partly, to the energy required to overcome the friction caused by the sealings and guides, and partly to the zero error of the traditional pressure gauge and is, with respect to the 150 kp/cm^2 maximum amplitude of the instrument, roughly about ± 4 kp/cm^2.

The above measurement results reveal that Eq. (16) is excellently suitable for the calculation of the energy required for technological purposes. Thus, in technological applications, the impact efficiency may be considered as equal to 0.94.

Summary

The authors report on the development of a new equipment to measure the relative speed of the moving parts of pneumomechanical HERF machines at the moment when the upper part of the die just impacts with the billet. Connecting this measurement with the Waterman-test they determined the utilized energy at blow, the energy of the blow and so the efficiency of the blow.

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