THE DESIGN AND CONSTRUCTION
OF A TORSION IMPACT MACHINE

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This is to certify that the

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THE DESIGN AND CONSTRUCTION OF
A TORSION IMPACT MACHINE

by

Paul J. DeKoning

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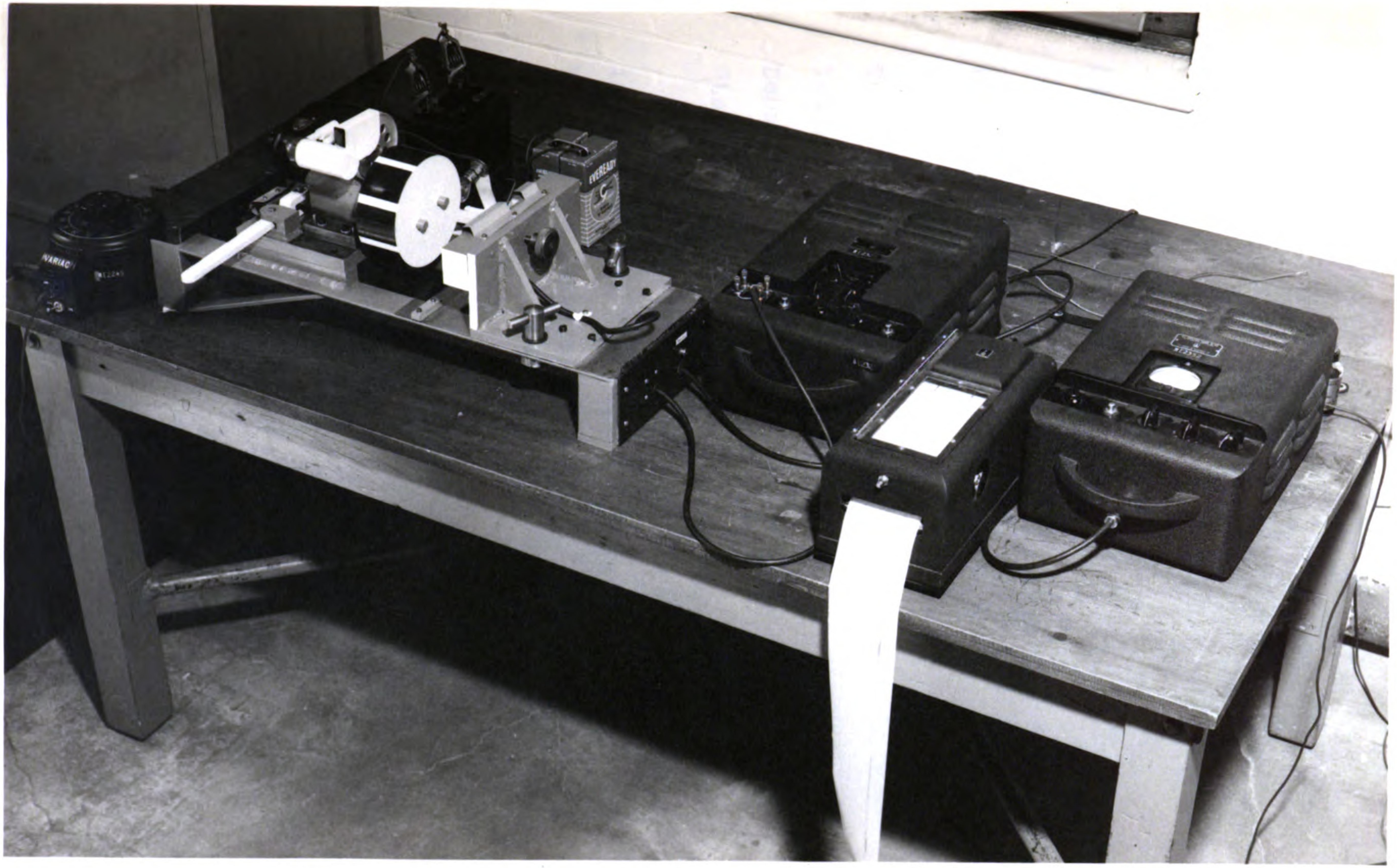

TORSION IMPACT MACHINE
AND
OSCILLOGRAPHIC RECORDER

Acknowledgement

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The author further acknowledges the helpful interest of Dr. Rolland T. Hinkle, also of the Mechanical Engineering Department at Michigan State College

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THE DESIGN AND CONSTRUCTION OF
A TORSION IMPACT MACHINE

Introduction

This paper presents the features of design and construction of a Torsion Impact Testing Machine. Design problems include calculations for rotational energy and torque values, a stroboscopic speed-set and synchronizer, a photo electric tachometer, and the application of wire resistance strain gages with their related equipment. Along with the machine development was included the design of a particular specimen for the test.

It is felt that the machine as produced will have a useful part to play in the field of Materials Testing. It is therefore offered as a new type of instrument and test for research in strength of materials.

Historical

The testing of materials under conditions of shock or impact loading has been tried by a number of investigators in recent years. The most familiar test of this nature are made with the Izod and Charply impact instruments. Each uses a specimen peculiar to itself and has a characteristic way of holding it, but both methods of testing subject the material to shock loads in tension and compression. The Izod and Charpy tests employ notched specimens loaded as beams, one as a cantilever, the other as a simply supported beam. These tests have proved somewhat successful in finding energy absorption values for steels of various heat treatment and operating temperatures.

The Izod machine also has provision for testing a small specimen in direct tension under an impact load. While it is true that quantitative design factors cannot be obtained from these two impact tests, it is possible for the results to help explain some material failures which can't be accounted for on the basis of standard tension tests. A case in point is that discussed by Mr. D. F. Windenburg, the chief physicist at the David Taylor Model Basin[1]. He cites the difficulty experienced with welded ship plates which fractured in service. Careful preliminary and post failure tests made on the plate material showed proper physical characteristics, according to the A.S.T.M. specifications for tensile strength and ductility. Even though the steel appeared satisfactory, it actually failed in service resulting in the sinking of several welded type ships both at the dockside and on the high seas. When Charpy impact tests were made on the steel used, it was discovered that operating temperatures had much to do with the energy absorption ability of the material. The notched specimens used and the impact loading similated conditions of very high stress concentrations which seemed to be present in certain parts of the ships' plates. The impact tests showed sharpt transition from high to low energy values in the temperature range from -40°F to +30°F. These data showed that the steel used was extremely sensitive to stress concentration at such operating temperatures. Such information was not evident from standard tests, but did appear in the impact tests.

Others have felt the insufficiency of the standard tests and have devised additional tests based on dynamic stress conditions. D.S. Clark and G. Datwyler[2] carried out some work with materials under the direct tension impact loading method of the Olsen Izod machine to which they adapted a specimen holder dynamometer. They found dynamic stresses about 20% higher than static, elongations 16-120% greater and reduction of area from 9-191% higher. While these data tend to demonstrate the value of dynamic loading, they do however, show considerable variation. H.C. Mann[3] objects to this method on the basis of error due to the interference of the natural frequency of the machine and dynamometer bar. W.H. Hoppmann[4] used a guillotine type machine where a falling tup strikes a smaller weight attached to a small tension specimen. Force vs time data were obtained by use of electric strain gages and oscillographs. Energy absorption values were measured by a spark system.

H.C. Mann[3] investigated behavior of small specimens under tension impact loading. He used a machine which consisted of a rotating disc with striking horns actuated mechanically through a shallow spindle. The tensile specimen was mounted with a tup on to a pendulum type bracket. Movement of this bracket was measured by means of a cam arrangement and dial gage. Energy values were computed by the following expression:

$$E = w_o(1-\cos\theta)^{\frac{1}{2}}K_1 - (1-\cos\theta)K_2$$

where K_1 and K_2 are machine constants

w_o is the angular velocity of the disc

θ is the angle of pendulum swing

Besides the above mentioned tests which have to do primarily with tension loading, there have been others devised which subject a specimen to impact loads in torsion. Noteworthy among several are the two following methods.

Mititosi Ithihara[5] developed a test which used a specimen as shown in Fig. 1.. With this machine, torque loads were measured by a spring system and the angle of twist through optical means. The latter was recorded on a revolving drum as a function of time. With this set-up he found dynamic torques 25% higher than static values. Twist angles were 10-20% larger in dynamic torsion. In general it was found that maximum torque increased as the velocity of deformation increased.. However, this method was criticized by N. Manjoine[6]. He felt that the test section of the specimen was too constricted, the l/d ratio of 1.25 being so small as to give a poor distribution of torsional stress.

A slightly different type of torsion impact test has been conceived by Luerssen and Greene[7] in their efforts to evaluate hardened and tempered steels. This method does not attempt to determine the actual stresses set up in a specimen under torsion impact. It merely measures the energy required to fracture specimens subjected to sudden twisting. The type of specimen used is shown in Fig. 1. As can be seen these have considerable

TORSION IMPACT SPECIMENS

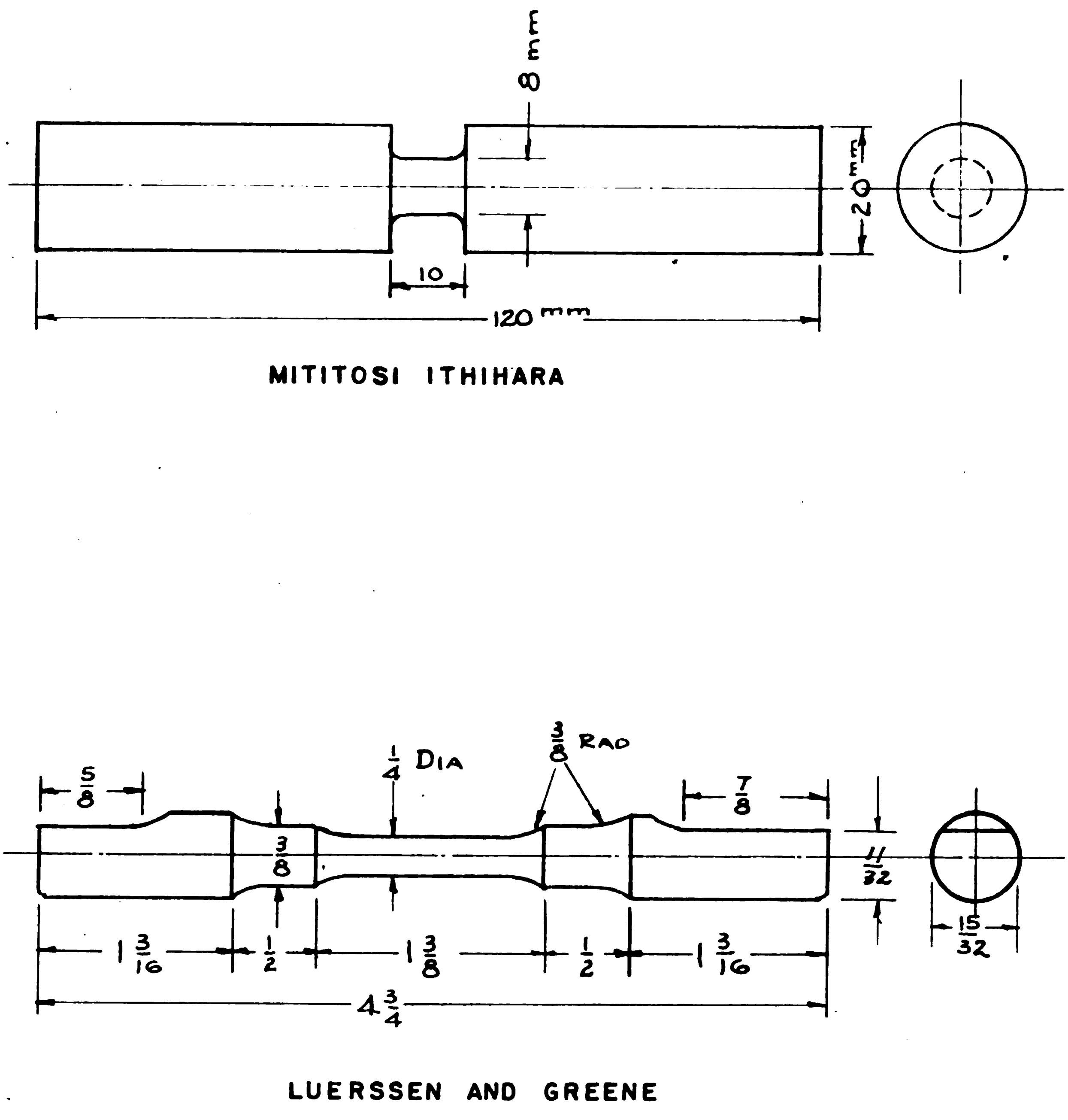


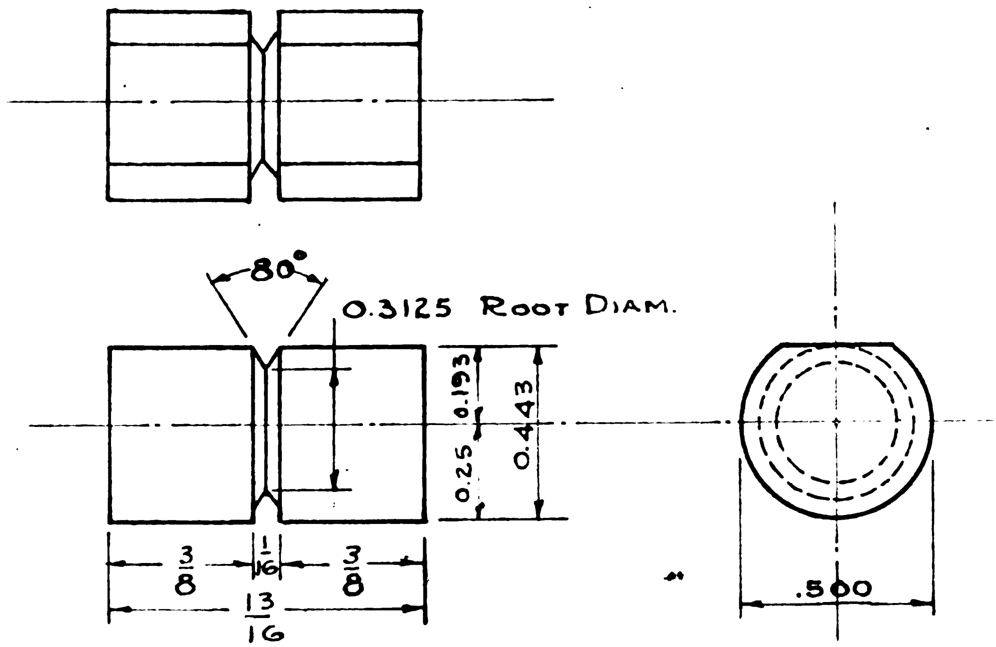
Fig. 1

overall length and a full test section length of one inch. The machine itself consists essentially of three major parts: the energy unit, a heavy flywheel rigidly connected to a shaft is mounted on anti-friction bearings, and these in turn are set in the housing. The flywheel has on its face two symmetrically located striking bosses which engage a tup fastened to one end of the specimen that protrudes from its holder in the sliding head. The specimen is fractured by quickly sliding it and its tup in to mesh with the striking bosses on the rotating flywheel. The flywheel is previously brought to testing speed by means of a small motor. Its speed is measured by a direct connected tachometer. As the specimen is ruptured, energy from the rotating wheel is absorbed so that a speed change is noted. This is measured by the tachometer and energy values are thus determined. Several different testing speeds and energy levels are available, such as 77 ft. lbs. at 391 rpm, 111 ft. lbs, at 472 rpm, and 147 ft. lbs. at 543 rpm.

Results of several tests on various steels heat treated in different ways show this type of test to be quite useful. Several variables not previously considered in quantitative testing of very hard steels can be detected. Furnace atmosphere has an influence on torsional impact resistance. Time of soaking, length of tempering time, and other factors also are shown to be critical through the data of this type of test.

Inasmuch as impact tests do reveal material characteristics not shown by the standard tests, they would appear to be of some value. This is particularly true of the torsion impact test. In the case mentioned above where Luerssen and Greene used a specimen having a test section at least 1" long. There was considerable energy involved in twisting the material within this length. And since this energy is critically affected by techniques in heat treatment, this type of test is sensitive to such factors and is therefore useful. However, this method does not indicate anything with regard to notch sensitivity. This factor is important in the matter of stress concentrations. It is measured to some extent in the Izod and Charpy impact tests since the specimens are of the notched type, and are arranged to resist tension and compression stresses at the notched section.

In view of the above, there seems to be a need for a slightly different kind of test which would supplement the torsion impact method of Luerssen and Greene; a test which would tend to show something concerning notch sensitivity of materials under torsional stress. The chief purpose of the project discussed in this paper,



SCALE - 2" = 1"

ACTUAL SIZE

VEENOTCH SPECIMEN

Fig. 2

therefore, is to devise such a test. This involves the design of a proper test specimen and the necessary apparatus for testing it.

Description of the Specimen

The specimen for the proposed test is shown in Fig. 2. Dogs for gripping the piece are arranged so they are exactly 1/16" apart, giving a zero length at the bottom of the "V" notch. Reasons for the choice of this small size specimen will be brought out in the subsequent description of the test. This type of specimen was chosen since it was desired to produce a condition of stress concentration in the region of a notch in order to test for notch sensitivity. That such conditions are met with this specimen is shown in the following manner.

Consider the section of Fig. 3 representing the plane of shear under stress, and a length of material.

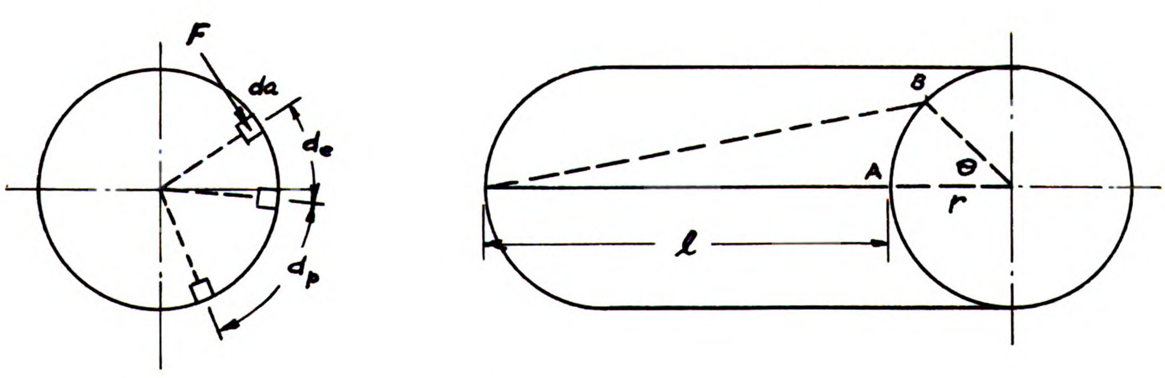


Fig. 3

With torsion forces acting on the section, the element da would tend to move from position A to B. The energy required for this would be $W=F(d_e + d_p)$ where d_e is the arc moved through under elastic deformation and d_p is the arc of plastic deformation up to the time of fracture. From Fig. 3 the value of d_e would be:

$$d_e = r\theta = \delta l$$

where δ = unit strain in shear

l = length of the test section

But since $l = 0$ for this specimen, then $d_e = 0$, and thus $W = F\,d_p$. Theoretically there is no elastic energy involved in fracturing the specimen on the shear plane. Any energy absorption during the rupturing of the specimen would therefore be due to the plastic deformation of metal crystals in the plane of shear. But even with an extremely sharp notch, there probably would be a slight elastic behavior of the material in the regions on each side of the shear plane. Thus it is evident that this type of specimen should reveal variations in material strength which would be due to notch sensitivity, and would tend to show the ability of materials to overcome stress concentrations.

General Features of the Testing Machine

The machine designed for testing the specimens just described is shown in Figs. 4 and 5. It consists fundamentally of a flywheel which is brought up to a predetermined speed to supply the rotational energy required to rupture a specimen in torsion. The wheel is mounted on ball bearings and is driven by a fractional horsepower motor through a friction arrangement. Motor speed is controllable through use of a Variac. Two striking pegs are located on the open face of the flywheel. Speed of the wheel is measured by a photo electric cell which is set up to "see" white spots spaced uniformly on the rim. The photo cell impulses are amplified by a Brush DC Amplifier and recorded on a moving tape by one pen of a Brush magnetic oscillograph. This gives a wave form, the frequency of which allows an exact measure of the flywheel speed without any mechanical connection to it. Initial wheel speed is set by means of the stroboscope synchronizer.

The specimen is held in a torque measuring socket fastened rigidly to the movable tail piece which can be slid back and forth on the bed to facilitate loading the specimen. The tail piece can be clamped firmly so that the specimen is tightly fixed in its support on the machine bed. When the flywheel is brought up to speed it is slid

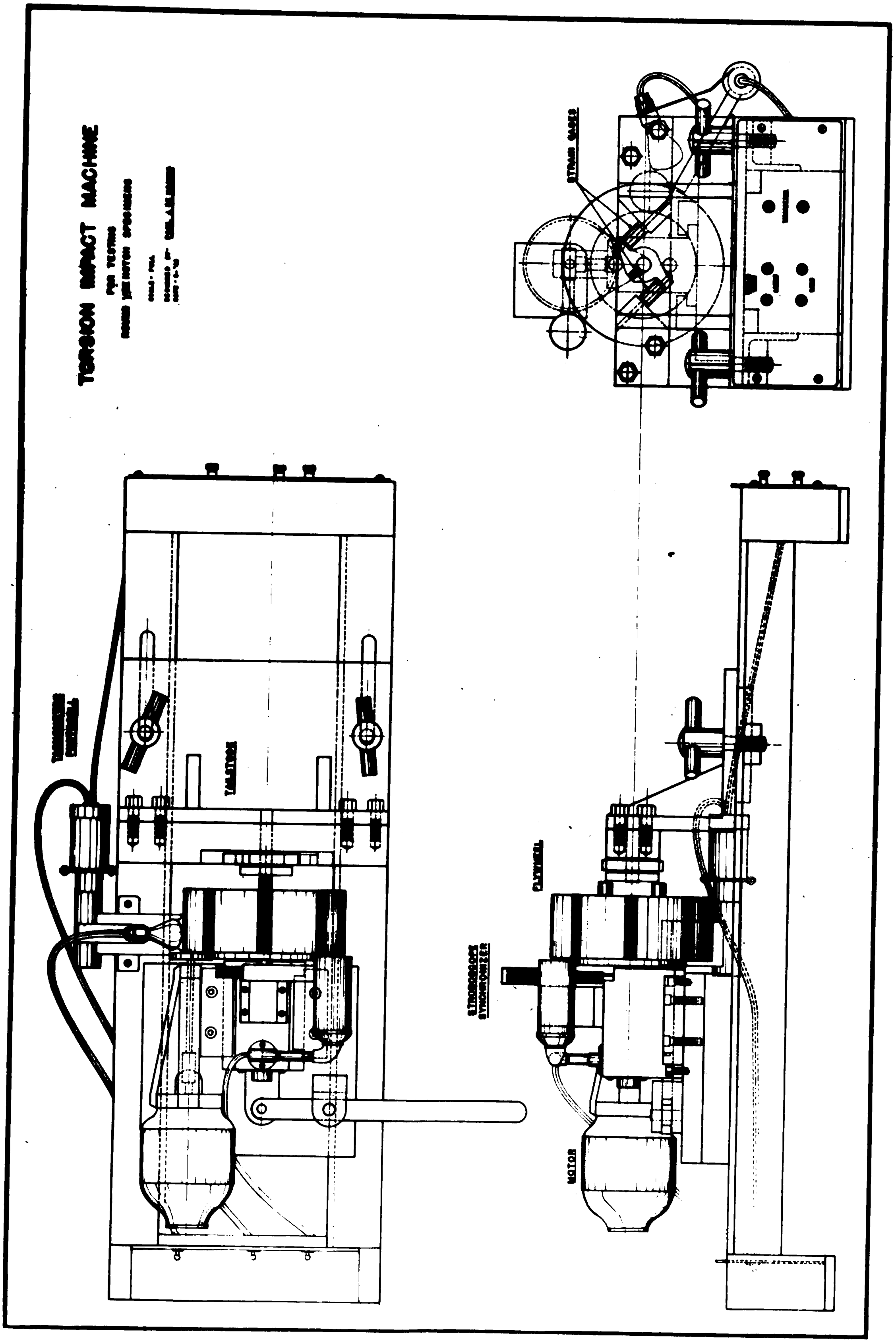

TORSION IMPACT MACHINE
STRAIN GAGES
FLYWHEEL
STROBOSCOPE SYNCHRONIZER
MOTOR

Fig. 4

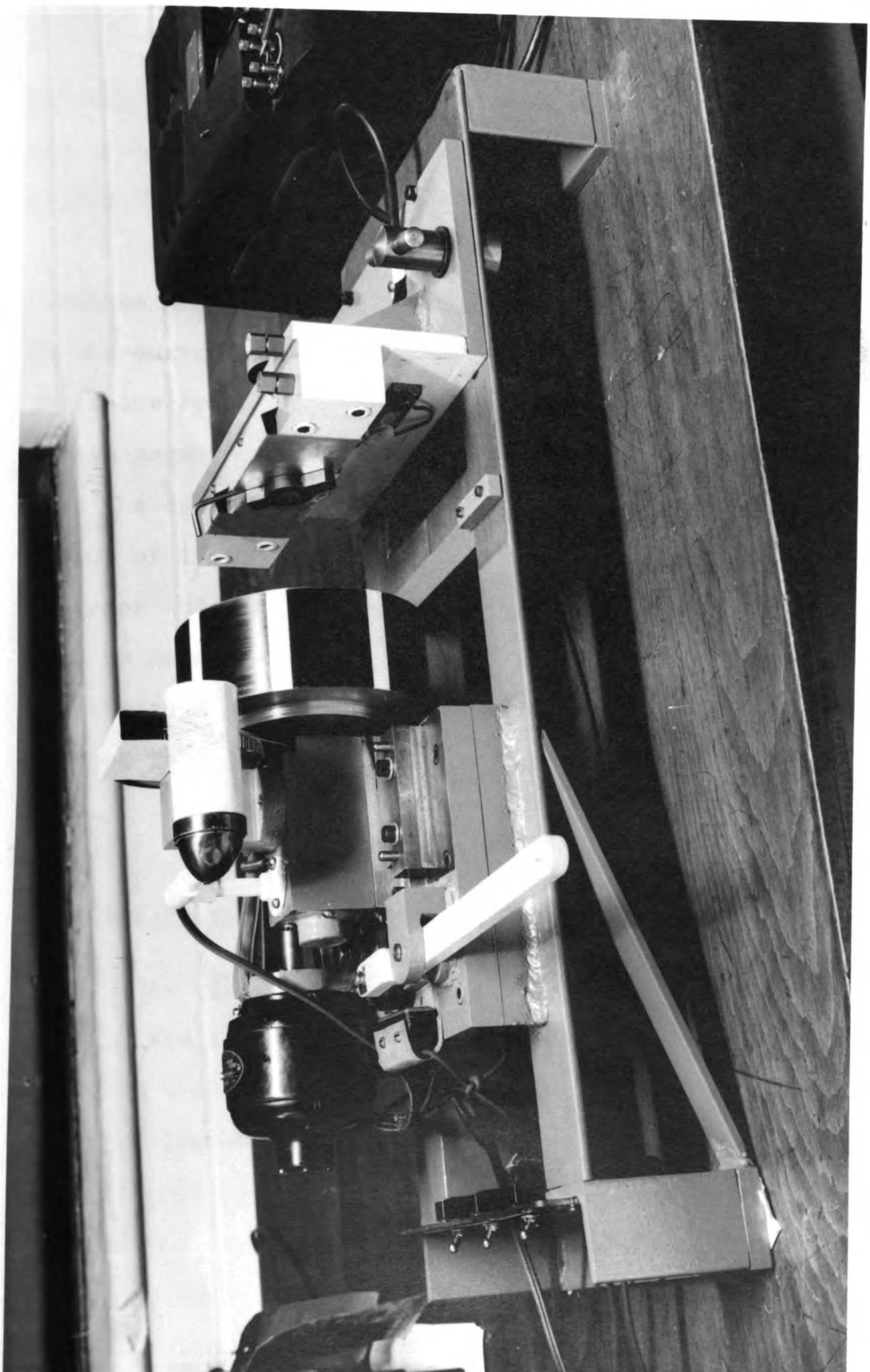


Fig. 5

quickly to the right until the pegs engage the twisting dog clamped on the free end of the specimen. Synchronization of the pegs with the dog will be discussed later.

Energy required to fracture the specimen is determined from the change in flywheel speed by referring to the curve shown in Fig. 8. Torque effort required to break the specimen is measured by means of resistance strain gages mounted on the two small pillars which connect the specimen holder to the buttress and tail piece. Output of these gages is interpreted by a Brush strain analyser and recorded on the second pen of the oscillograph used to measure speed change of the flywheel. Thus a simultaneous record of energy absorption and torque developed is produced on the paper of the oscillograph.

Description and Design of Components

1. Flywheel

The determination of flywheel size and speed is based on the amount of energy required to fracture a test specimen of the type adopted for this impact test. Some assumptions must be made regarding the actual behavior of the specimen. As was noted before, the material is subjected to shear stress on a plane in the center of the "V" notch. Energy required to fracture such a piece can be approximated in the following manner:

Energy

Data taken from a typical static torsion test of a piece of SAE 1020 cold rolled steel shows a total angle of twist at rupture of 5π radians and an approximate average torque of 18000"#. Specimen diameter was 1.061" and test length was 10". Reference to the curve of Fig. 6 shows that most of the energy required to break the material is in the plastic range. Hence the use of an average torque of 18000"#. Total energy under these conditions is therefore:

$$U_t = T\theta = 18000 \times 5 = 282,000"\#$$

U_t = total energy (approximate)

T = average torque in the plastic range

θ = angle of twist of test length in radians

Dividing U_t by the volume of the test length gives the energy required per cu. in. of material.

$$U = \frac{282000 \times 4}{\times 1.0612 \times 10} = 32000"\#/\text{cu. in.} = 2660\ '\#/\ \text{cu. in.}$$

Now to arrive at the energy needed to fracture a specimen of the type and size used for this test it can be assumed that there is no "V" but merely a cylindrical section of .3125" x .0625". The "V" notch would actually reduce the energy required so the above assumption will suffice to give a required energy level. The volume of this assumed test section is:

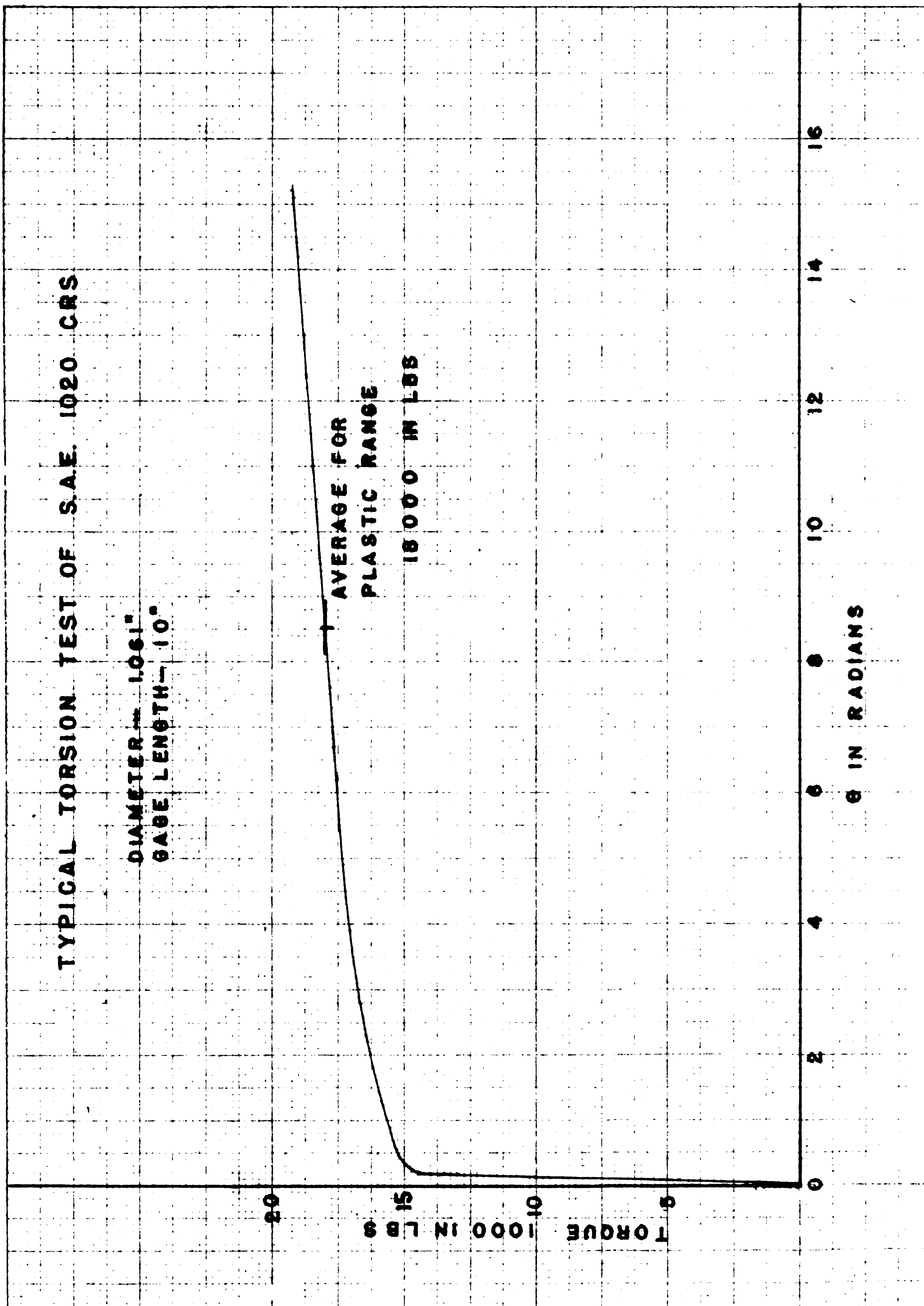

TYPICAL TORSION TEST OF S.A.E. 1020 CRS
DIAMETER = 1.061"
GAGE LENGTH = 10"
AVERAGE FOR PLASTIC RANGE
18 000 IN LBS
θ IN RADIANS
TORQUE 1000 IN LBS
0
2
4
6
8
10
12
14
16
5
10
15
20

Fig. 6

$$V = \frac{\pi \times .375^2}{4} \times .0625 = .00688 \text{ cu. in.}$$

(Let the average diameter be .375")

Therefore the energy needed would be

$$UV = 2660 \times .00688 = 12.7 \text{ ft. \#.}$$

It is recommended that the magnitude of residual energy in the flywheel after rupture of the specimen be at least 25% of the initial energy[6]. Therefore 12.7 ft. # = .75 E_t so that the required flywheel energy level equals E_t = 17 ft.#. Since the material used to compute this energy is SAE 1020 it can be assumed that the 17 ft.# will be sufficient for less ductile materials such as heat treated steels, and cast irons and non-ferrous materials.

Speed

To arrive at the exact size of a flywheel which will provide at least 17 ft.# of energy, one must also know the speed of rotation. Several questions arise concerning the proper speed. How high can the initial speed be and still not jeopardize proper engagement of the striking pegs with the twisting dog? What effect does initial speed have on values of energy absorption by the specimen? How large a flywheel can be tolerated, and a fourth, how will initial speed affect the change in speed caused by a given energy absorption?

The first question can be answered by saying that initial speed is not critical providing that an effective method of synchronizing is used. Such a method has been designed and will be discussed later. The second question is answered by reference to the work of Stout and Greene who found that variations in initial speeds had practically nothing to do with values of energy absorption[9]. The third question is answered by simply letting the flywheel be of convenient size for the apparatus.

The fourth question must be answered more at length. One of the chief factors of interest in this torsion impact test is notch sensitivity. Since it seems desirable to note carefully and accurately any variation in material strength of the specimens under various degrees of heat treatment, and since these energy variations may be small, it is important that the flywheel be sensitive enough to register small energy changes by appreciable changes in speed. Initial speed has a definite effect on speed change for a given energy absorption value. The higher the initial speed, the smaller will be the change in speed for a specific energy change. This can be shown in the following manner:

Let the energy change be ΔE (1)

$$\Delta E = \frac{I}{2}(w_I^2 - w_F^2) \text{ where}$$

w_I = initial speed in radians

w_F = final speed after the specimen is broken

I = the flywheel moment of inertia

Let us take two conditions where w_{I_1} and w_{I_2} equal two different initial speeds and w_{F_1} and w_{F_2} are the corresponding final speeds. Let ΔE be a constant and of course I will be the same for both conditions.

Since $\Delta E_1 = \Delta E_2$ and $I_1 = I_2 = I$, then from (1)

$$(w_{I_1}^2 - w_{F_1}^2) = (w_{I_2}^2 - w_{F_2}^2)$$

or

$$w_{F_2} = \sqrt{w_{I_2}^2 + w_{F_1}^2 - w_{I_1}^2}$$

Now when values are assumed as follows:

	w_{I_1}	w_{F_1}	w_{I_2}		w_{F_2}	Δw
a.	40	20	<u>60</u>		49	<u>11</u>
b.	40	20	<u>80</u>	Then	72	<u>8</u>
c.	40	20	<u>90</u>		83	<u>7</u>

it is evident that if $w_{I_{2_b}} > w_{I_{2_a}}$

then $\Delta w_b < \Delta w_a$

and if $w_{I_{2_b}} < w_{I_{2_c}}$

then $\Delta w_b > \Delta w_c$

This means that for a given value of I and a constant energy change, the flywheel speed shows a greater change as its initial speed if lowered. From this it seems that the initial speed should be kept as low as possible to insure good sensitivity for the apparatus. A curve showing speed change plotted against initial speed for the above example is shown in Fig. 7.

The choice of an exact initial speed for the flywheel involves a compromise. For good sensitivity it should be low, for ease of engagement it should be low, and for the required energy value it may be low if the wheel size is reasonable. After taking these factors into account and making a few preliminary calculations, it was decided to use an initial speed of 420 rpm, or 44 radians per sec. On this basis the size was computed.

The rotating mass is made up of three distinct parts: the shaft, the friction drive rim, and the flywheel itself. As far as the striking pegs are concerned, they can be assumed to be a part of the flywheel since they were pressed into the wheel in holes which are as deep as the pegs themselves are long.

First the respective moments of inertia are:

<u>a</u> for the shaft:

$$I = \frac{\pi h W r^4}{2g}$$

$r = .25'' = .0204$ ft.

$h = 4'' = .333$ ft.

For steel, $W = 485$#/cu. ft.

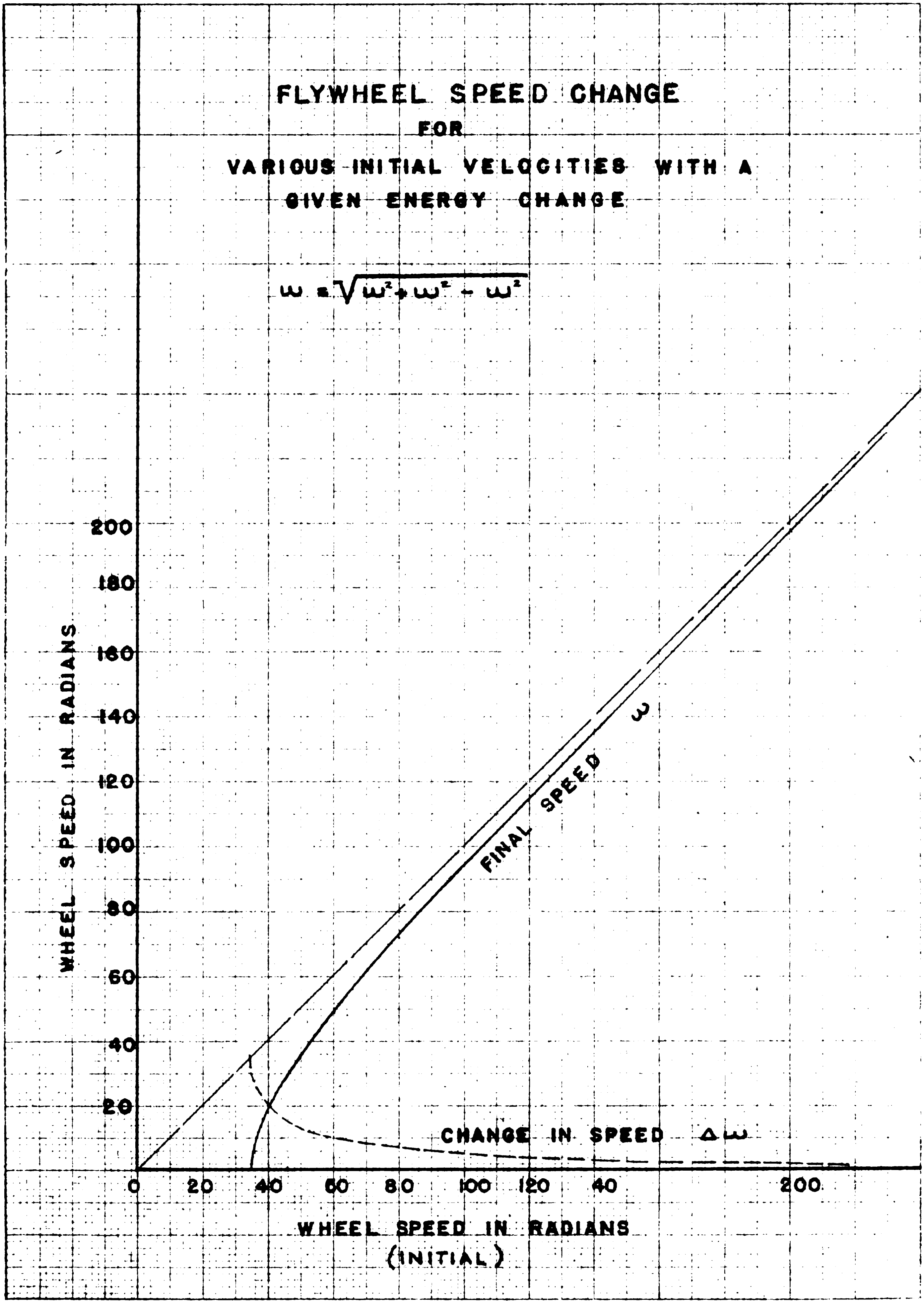

FLYWHEEL SPEED CHANGE
FOR
VARIOUS INITIAL VELOCITIES WITH A
GIVEN ENERGY CHANGE
$\omega = \sqrt{\omega^2 + \omega^2 - \omega^2}$
WHEEL SPEED IN RADIANS
200
180
160
140
120
100
80
60
40
20
FINAL SPEED ω
CHANGE IN SPEED $\Delta\omega$
0
20
40
60
80
100
120
40
200
WHEEL SPEED IN RADIANS
(INITIAL)

Fig. 7

$$I = \frac{\pi \times .333 \times 485 \times .02^4}{2 \times 32.2} = .00000253 \text{ in}^4$$

b for the friction disc:

$$r = 2" = .1666 \text{ ft.}$$

$$h = 5/16" = .026 \text{ ft.}$$

For steel, $W = 485$ #/ cu. ft.

$$I = \frac{\pi \times 485 \times .026 \times .166^4}{2 \times 32.2} = .0029 \text{ in}^4.$$

c for the flywheel mass. This must be found from the energy equation $E_t = \frac{1}{2}w^2 \left[I_s + I_D + I_F \right]$

where E_t = 17 ft# the previously determined required energy

w = 44 rad/sec as above

I_s = moment of inertia for shaft (small enough to be neglected)

I_D = moment of inertia of the friction disc

I_F = moment of inertia of the flywheel from which the size can be determined.

Therefore

$$E_t = 17 = \tfrac{1}{2}(44)^2 \left[.0029 + I_F \right]$$

$$\text{and } I_F = \frac{17 - 2.81}{970} = .0146 \text{ in}^4.$$

Now, for convenience, a flywheel diameter of 6" was chosen. Thickness is found as follows:

Since $I_F = \frac{\pi h W r^4}{2g}$ and $r = .25$ ft.

$$h = \frac{I_F \times 2g}{\pi W r^4} = \frac{.0146 \times 2 \times 32.2}{\pi \times 485 \times .25^4} = .1575 \text{ ft.} = 1.96''$$

This 1.96" is under what could be tolerated in the general design of the machine so it was decided to let E_t = 20 ft.#. With this new energy level the value of h was found to be 2.335". This was used as the flywheel thickness, the diameter being 6".

2. Synchronizing Device

Having chosen a speed of 420 rpm for the flywheel, it was necessary to devise a method of setting the wheel at that initial speed. As thought was given to this it became evident that the same mechanism could be made to serve also as a synchronizer. Synchronization is needed to insure proper engagement of the rotating striking pegs with the stationary torque dog fastened to the specimen. This combined speed set and synchronizer is described in the following paragraphs.

A small auxilary wheel made of aluminum and mounted on ball bearings is driven by a rubber belt from the flywheel shaft. The speed ratio of this wheel relative to the shaft is 1 to 7. This means that when the flywheel rotates at 420 rpm, the synchro wheel will make one revolution per second. A 110 volt neon glow lamp is arranged to shine on a portion of the rim of the small wheel. This illuminated section is observed through a peep hole or simple eye piece. Spots are painted on the wheel rim exactly 3° apart. The spacing of these spots is such that with 120 pulsations per second produced by the neon lamp, they will "stand still" at the correct 420 rpm flywheel speed. Thus when an observer sees the stationary spots he knows the flywheel has attained its proper initial velocity.

To make this speed setting device a synchronizer is a simple matter. Instead of painting spots on the entire rim of the small wheel, merely use approximately seven eighths of the rim surface for the spots. This causes the spots to appear stationary for 7/8 of a second and black out for one eighth second. Thus a pulsation is produced every second as the operator observes the wheel rim. To synchronize the pegs on the flywheel with the twisting dog it is only necessary to set them clear of the dog and then "tie in" the blank spot on the synchro wheel rim with this position. Under this condition, the pegs will always be clear of the dog when the dark pulsation occurs on the synchro wheel. Engagement can take place at any time so long as it is instituted in rhythm with the pulsations.

Since the flywheel makes seven revolutions to one of the synchro wheel, the pegs will always clear the dog, thus permitting proper engagement.

3. <u>Tachometer</u>

Measuring accurately the speed of the flywheel before and after fracturing a specimen is important. Since it is desired to obtain absorbed energy values, the exact flywheel speed must be known at all times during a test. Furthermore, since the initial energy level of this machine is low (20 ft. lbs.) it would be inadvisable to measure the speed with any kind of mechanical tachometer because of the lost energy involved in driving it. The device chosen as a tachometer for this instrument was a photo electric cell used in combination with a Brush DC amplifier and magnetic pen oscillograph. A photo cell is arranged so as to face the flywheel rim upon which are painted eight white spots. These spots are illuminated by a 32 candlepower light operated by a storage battery. The photo cell is connected in series with a 10 meg. ohm resistor to a 90 volt DC power supply. Tapped across the resistor are two wires that lead to the DC amplifier which is a complete unit manufactured by the Brush Development Co. It is capable of amplifying very small DC phenomena enough to run a magnetic pen oscillograph. The oscillograph has a low inertia pen that traces a variable on a moving strip of paper. Thus, a record of the photo cell pulsations is obtained on the moving tape from which the exact flywheel speed can be found. The determination of wheel speeds is accomplished as follows:

With eight white spots on the wheel rim, a speed of 420 rpm will give 56 pulsations per second through the photo cell. These pulsations are recorded on the oscillograph as a sharp crested wave form. The wave length is a function of the pulsations and the chart speed. The recording tape or chart moves 125 mm per second; so for the initial wheel speed of 420 rpm the wave length will be $= \frac{125}{56} = 2.23$ mm. It is evident that any flywheel speed can be found by measuring the wave length produced by that speed and then solving for the rpm.

Example: let $\lambda = 3$ mm.

$$\therefore 3 = \frac{125}{8 \times \text{R.P.S.}}$$

$$\text{R.P.S.} = \frac{125}{3 \times 8} = 5.2 \quad \text{or rpm} = 312$$

Getting the exact speed is incidental to the final result desired which is actually the energy change caused by breaking a specimen. Since this energy change is a function of the change in speed, it is a simple matter to arrange a curve giving the desired energy change for any final fly wheel speed.

$$\Delta E = \tfrac{1}{2} I \left(w_1^{\,2} - w_2^{\,2}\right)$$

where ΔE = energy change or absorption

I = flywheel moment of inertia

w_1 = initial flywheel speed 44 rad/sec.

w_2 = final flywheel speed after specimen breaks.

The apparatus as designed gives the following analysis:

Let λ = wave length on tape

Q = tape speed; 125 mm/sec. = 4.92 in/sec.

f = frequency of pulsations produced by photo cell

$k = 8$ = spots on wheel rim or pulsations per revolution

n = final wheel speed r.p.s.

Then $w_2 = n2\pi$

and $\lambda = \frac{Q}{f}$ or $f = \frac{Q}{\lambda}$

and $n = \frac{f}{k}$

$$\therefore\ w_2 = \frac{Q\,2\pi}{\lambda k}$$

Substituting the machine constants as given above:

$$w_2 = \frac{4.92 \times 2}{8\lambda} = \frac{3.87}{\lambda}$$

where w_2 is in radians and

λ is measured in inches.

Using equation (1)

$$\Delta E = \tfrac{1}{2} I \left(44^2 - \frac{3.87^2}{\lambda^2}\right)$$

$$E = K_1 - \frac{K_2}{\lambda^2} \qquad \text{where } \frac{I}{2} = .009$$

$$K_1 = \tfrac{1}{2} I \, 44^2 = 17.48$$

$$K_2 = \tfrac{1}{2} I \, 3.87^2 = 0.135$$

Therefore $\Delta E = 17.48 - \dfrac{0.135}{\lambda^2}$

This enables one to plot a curve of ΔE against λ where λ can be quickly measured on the oscillograph tape. This curve is shown in Fig. 8. Here it is convenient to plot values of 10λ since these can be measured more accurately than λ itself. Absorbed energy can be found from this curve for any final flywheel speed as shown on the oscillograph tape. Measuring the energy absorption in this manner is extremely accurate because there is no mechanical connection between the photo cell tachometer and the energy mass. This method also gives a permanent record which can be studied at a later time if desired. It is also possible with this method to observe the manner in which the flywheel changes speed, and thus it gives a means of studying the transient behavior of the wheel as energy is given up to the specimen.

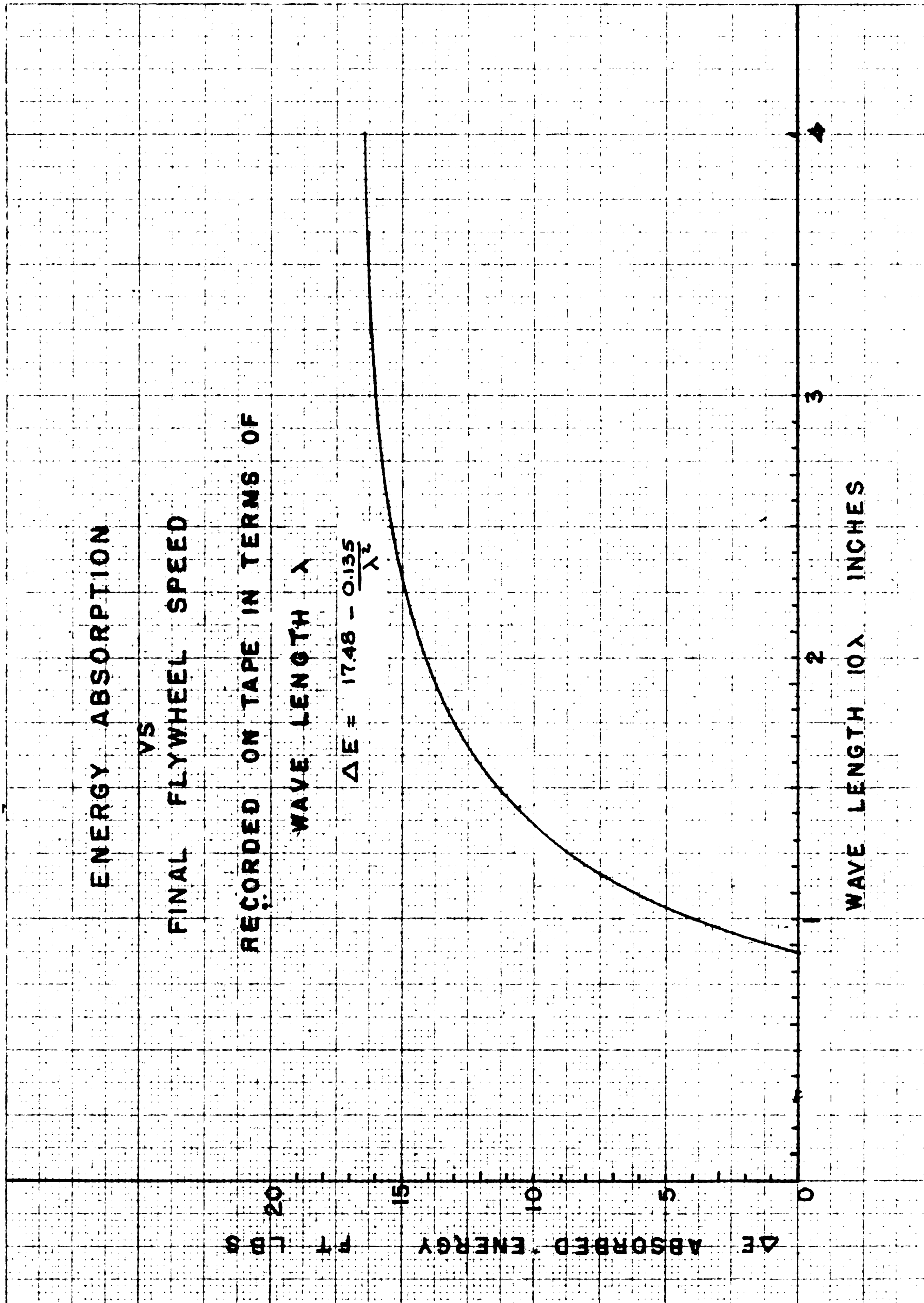

ENERGY ABSORPTION
VS
FINAL FLYWHEEL SPEED
RECORDED ON TAPE IN TERMS OF
WAVE LENGTH λ
ΔE = 17.48 − 0.135/λ²
WAVE LENGTH 10λ INCHES
ΔE ABSORBED ENERGY FT LBS
0
5
10
15
20
1
2
3
4

Fig. 8

4. <u>Torque Measuring Device</u>

The system for measuring the torque developed in twisting the zero gage length specimen is contained chiefly in the specimen holder. The stationary specimen holder is mounted on the tail piece of the machine in such a way as to cause the torque load to be resisted by two small pillars. These pillars, symmetrically located with respect to the center of rotation, are rectangular in cross section and of equal size. Details of this mounting can be seen in Fig. 4.

These pillars are each one inch long. They have their longitudinal center lines parallel to each other and exactly two inches apart. The torque will be transformed into simple compressive forces along the lengths of these pillars. Stress will be divided equally between them and the load in pounds on each will be equal to one half the torque. This is true because the lever arm for each pillar is exactly one inch long.

To arrive at a value for the torque developed by a specimen it is necessary to know the compressive force existing in one of the pillars. This force multiplied by one inch gives one half of the total torque. To obtain the compressive loads existing in the pillars, the unit stress is first found by the use of SR4 resistance strain gages. Multiplying the unit strain by Young's modulus for steel gives the unit stress and the unit stress multiplied by the pillar section area gives the required force and finally the torque.

Calculation is as follows:

$$\text{Torque} = T = 2 \times P \times 1''$$

$P = SA$ $\qquad$ S = unit stress psi

$S = E\delta$ $\qquad$ A = cross section area = $.1718''^2$

$E = 29 \times 10^6$

δ = unit strain

$$\therefore T = 2EA\delta$$

Torque is thus shown to be directly proportional to values of the unit of strain

Now δ is found by direct reading on a Brush magnetic pen oscillograph. Signals from the SR4 gages cemented to the pillars are fed into a Brush Strain analyser and thence to the oscillograph. Calibration of this oscillograph is given in microinches of unit strain. It is therefore feasible to read values of torque directly from the paper chart.

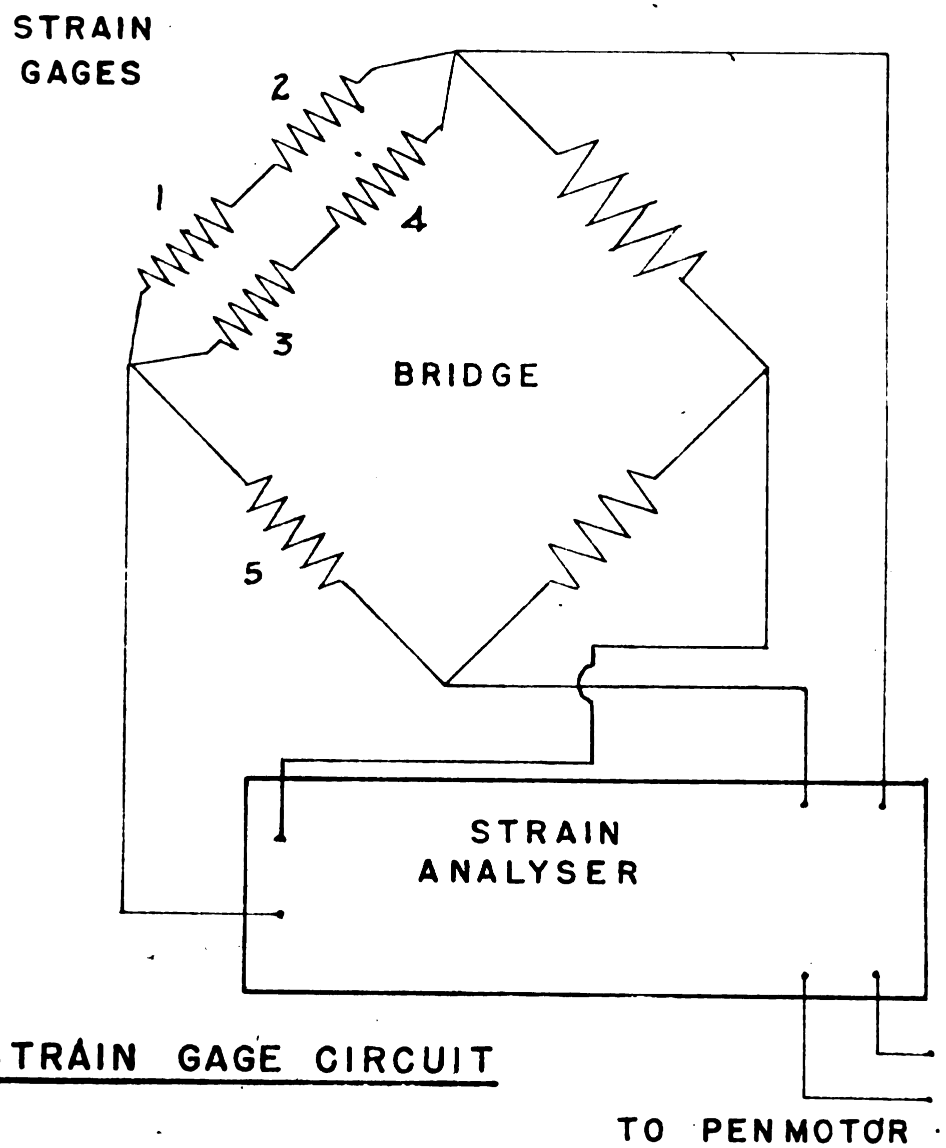
If we let δ = 1 microinch, then

$$T = 2 \times 29 \times 10^6 \times 10^{-6} \times .1718 = 10 ''\#$$

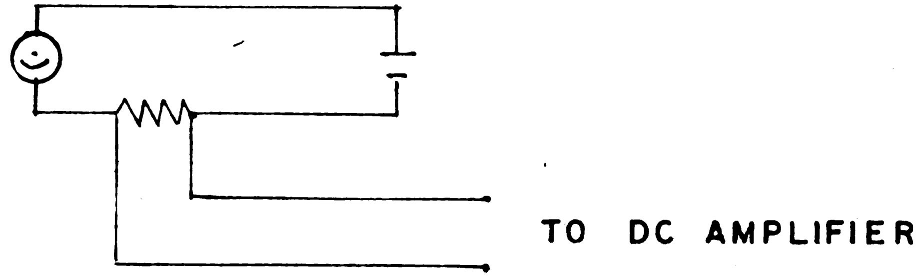
Therefore 1 microinch of strain will be equal to 10"# of torque. Multiplying the microinch reading from the chart by 10 gives the torque exerted in fracturing the specimen.

Not only is it possible to obtain torsion values but it is also true that the transient build up of the torque can be shown directly on the oscillograph chart. This allows a qualitative evaluation as well as quantitative. This record is made simultaneously with the energy absorption, so that quick and accurate comparison can be seen at a glance, since both records are side by side on the oscillograph tape.

The hook-up for the strain gages is of interest. A brief study of the torque pillars shows that they might be subject to a slight bending under the compressive loads. The l/k ration for the pillars is 9.3 so bending should not be troublesome, but it was thought best to arrange the strain gages in a way which would tend to average out the possible variations caused by bending. Two gages were cemented to each pillar. These gages are opposite each other on the widest sides. Both gages on one pillar are connected in series and the two pairs are then connected in parallel. See Fig. 9. This forms a composite system which actually becomes one active gage in the bridge of the Brush analyser. Each strain gage has a resistance of 350 ohms



STRAIN GAGE CIRCUIT



TACHOMETER PHOTOCELL CIRCUIT

Fig. 9

Compensation for bending in the pillars is thus obtained, and a true torque value is given because of this averaging arrangement.

<u>Preparation of the Specimen</u>

Because the specimen is small and of the shape it is, no difficulty is experienced in its preparation. It was decided to make the specimen of such a size so that the flywheel energy required to break it would be rather low. This in turn makes it possible to use a comparatively light flywheel which revolves at a medium speed. Under these conditions the test is very sensitive to small energy changes and hence is useful for showing effects of heat treatments and related factors. Furthermore, it was thought best to keep the specimen small in order that the torque loads at rupture would be light. This makes it possible to use a lightweight torque measuring device which is thus more sensitive to torque variations.

Machining of the specimens is best done by using one half inch round for stock. This is grooved first with a square nosed tool one sixteenth inch wide to a depth of 0.057". Next a sharp tool also one sixteenth inch wide but with an 80° point is moved in until the correct root diameter of .3125" is obtained. Uniformity of notch production can be assured by the use of this form tool procedure. Several specimens can be notched on one long bar and then the bar can be placed in a shaper or miller to produce the flats by allowing the cutter to move .057" into the metal from the one half inch outside periphery. After the flats are machined the individual specimens can be cut from the long bar. Heat treatment should be done in salt baths or an atmosphere controlled furnace. No machining after heat treatment is necessary except for an occasional touch up with a file on the outside to provide proper fit for the machine holder and striking dog.

Since the test is notch sensitive it is important to reproduce notches of exact shape and size from specimen to specimen. It is recommended that carboloy tools be used for machining and that frequent notch profile checks be made with an optical contour comparator.

Calibration of the Instrument

Calibration of the machine as far as torque measurement is concerned was accomplished by use of a simple lever arm which was clamped to a round bar similar to a specimen, which in turn was gripped in the torque measuring holder. The lever was twenty inches long and weights were hung on it to produce torque values. After properly balancing the Brush strain analyser the following results were noted when the antennator switch was set on 10 which gives a value of 10 microinches unit strain per line on the moving oscillograph tape:

Load	Lever Arm	Torque	Pen Deflection
5 lbs.	20"	100 in. lbs.	1 line
10 "	20"	200 " "	2 "
20 "	20"	400 " "	4 "
30 "	20"	600 " "	6 "

When it is recalled that previous calculation (page 32) showed a torque value of 10"# per one microinch of unit strain, it is evident that this agrees exactly with the calibration test.

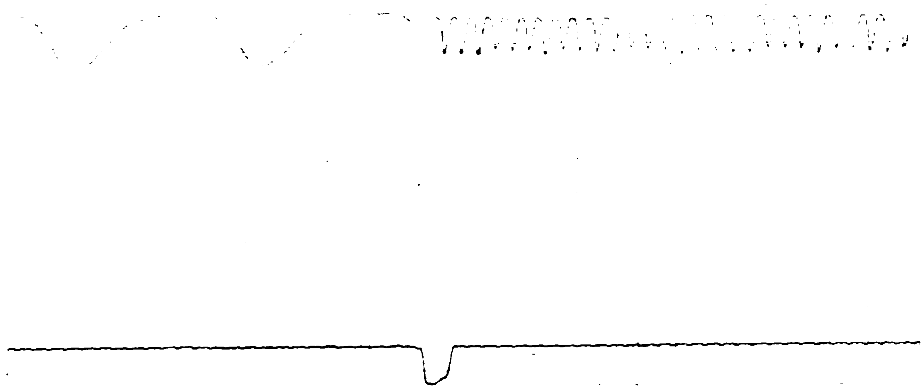
Proper calibration of the tachometer is assured by the correct layout of the white spots on the flywheel rim. A check on this showed exact results. At the correct flywheel speed of 420 rpm the tachometer wave length by measurement of 10 λ was precisely .0875". Dividing the chart speed by the number of pulsations per second gives λ, or $\frac{4.92}{56}$ in/sec = .0875".

Results

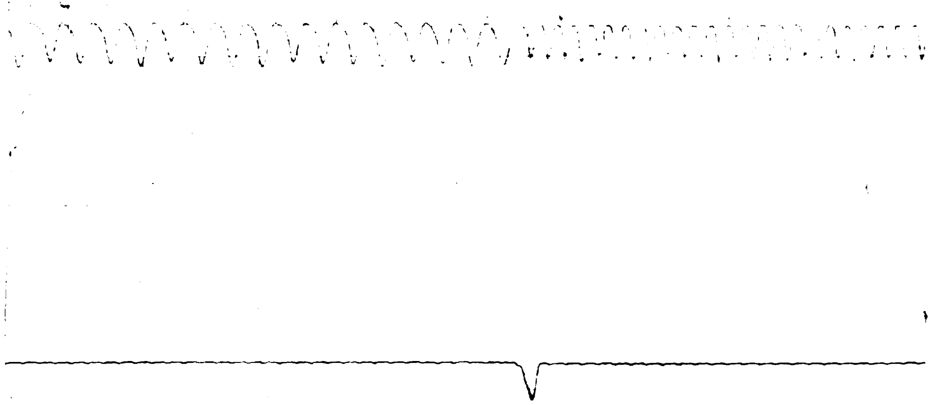
The results of the torsion impact test herein developed can best be seen by referring to the samples of oscillograph tape shown on page 39 . Pictured here are permanent and simultaneous records of the torque produced and the energy absorbed in fracturing vee-notched specimens of two kinds of material.

An effort was made to check the original calculations for energy loss and torque load for SAE1020 cold rolled steel. This did not prove too successful, probably because of the wide variations possible in such material. Actually the machine was unable to break the CRS specimen on the first trial. The flywheel stopped, and about 35° of twist was imparted to the specimen. On the second trial, of the same sample, it did fracture. In both cases however, torque values were clearly indicated. On the second trial, the flywheel speed change was evident in the wave length increase.

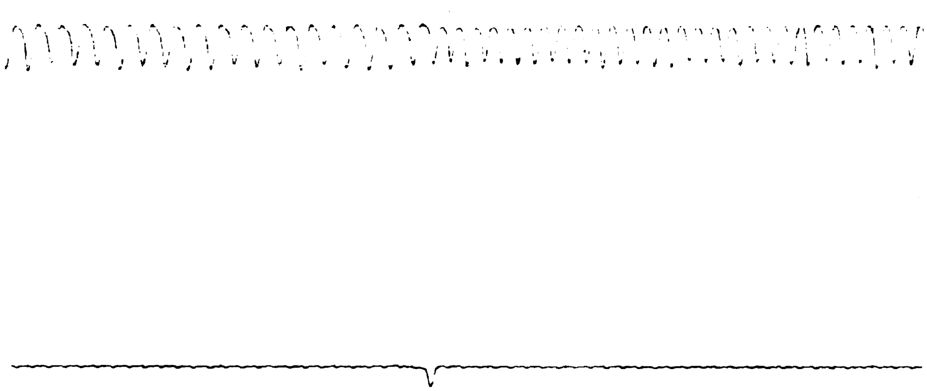
Another trial run is shown on the oscillograph tape at the bottom of page 39. This shows the behavior of another kind of material. It would appear from these records that the methods of measurement designed into the machine are satisfactory but that the capacity of the flywheel is somewhat inadequate for some ferrous materials.



SAE 1020 CRS
FIRST TRIAL



SAE 1020 CRS
SECOND TRIAL



BRASS

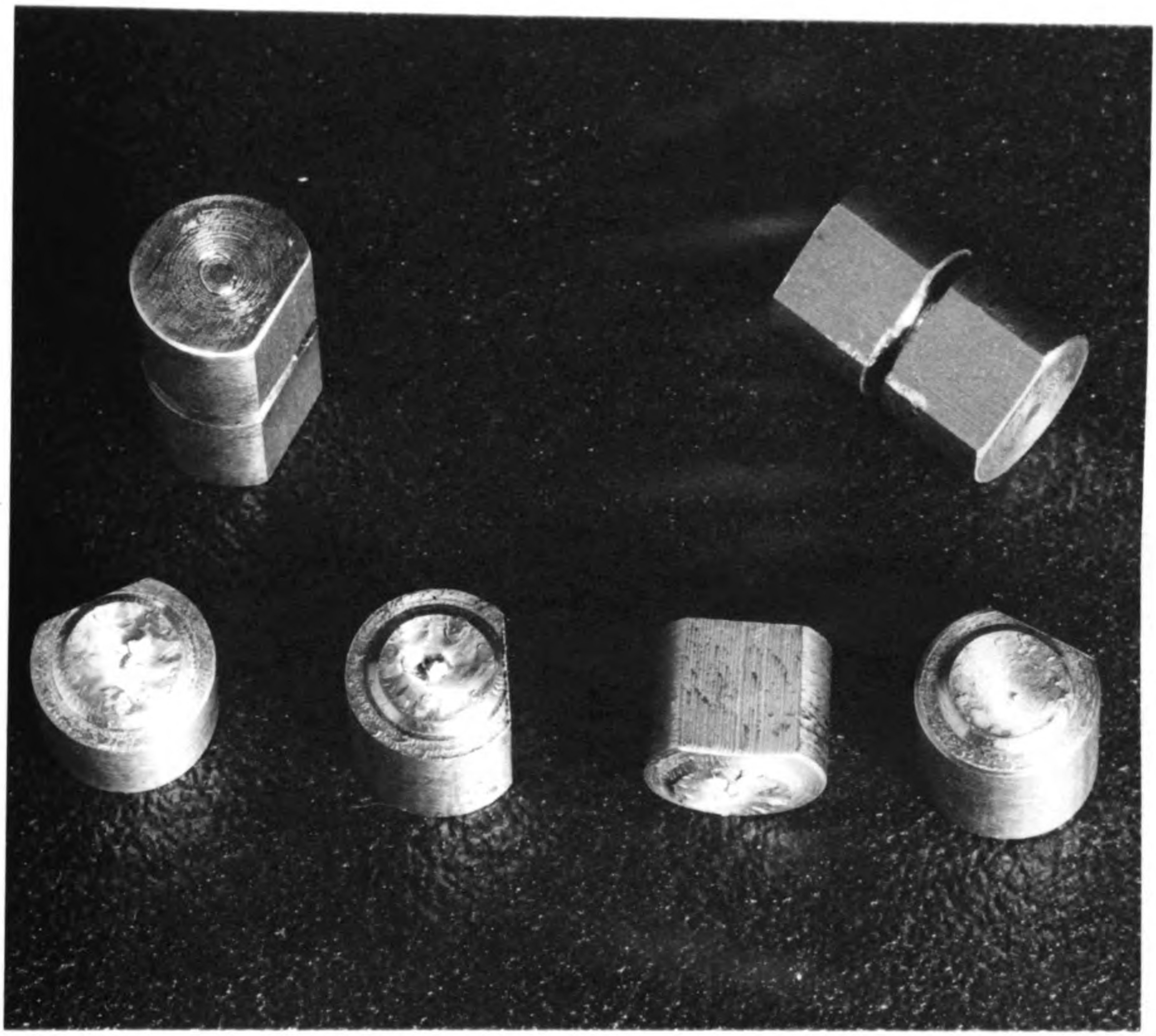


Fig. 10

This can easily be remedied by the use of a larger flywheel. The machine as it stands is useful for non-ferrous materials and is sensitive to small energy changes as was desired.

The specimens behave largely as intended. Results are shown in Fig. 10. They fracture on the shear plane at the root diameter of the vee notch. There is a fracture point in the center of the circular plane which indicates that little or no bending is present at the instant of impact. Some cracking was experienced in the heat treatment of several SAE 1090 specimens. More work will have to be done on the proper preparation of such samples.

Operating Procedure

If the following operating sequence is observed the Torsion Impact Machine will perform satisfactorily.

Electrical Connections

1. Neon glow lamp for the Stroboscope synchronizer -- 110 V. AC
2. Exciter lamp for the photo cell tachometer 6 V -- storage battery
3. Photo cell - 90 V. 2 "B" batteries

4. Driving Motor -- 110 V. AC

   Connected through a Variac transformer

5. Brush Strain Analyser and Brush DC Amplifier,

   110 V. AC

6. Strain gage leads - to Brush Strain analyser

7. Photo cell leads to

   Brush DC Amplifier through phone jack

Brush Recording Equipment

1. When proper connections are made turn on both analyser and amplifier and allow to warm up for about one half hour.

2. Balance both instruments according to instruction furnished.

3. With photo cell and exciter lamp on, adjust tachometer pen until an amplitude of approximately one half inch is obtained. Set antennator switch on .1 and secure proper amplitude with gain control rehostat. The flywheel must be revolving to do this. Use slowest chart speed for this adjustment.

4. Set oscillograph chart speed on highest value. Pull clutch shaft way out.

Testing Technique

1. Clamp a specimen in the striking dog, and then insert this assembly into the holder on the tail piece. Move tailpiece to its extreme forward position and clamp firmly.
2. Bring flywheel up to testing speed by means of the Variac. Observe illuminated rim of stroboscope wheel and note that at correct speed the spots will appear to stand still.
3. Observe the pulsations produced by the blank spot on the stroboscope wheel. Begin to count aloud and on the count of five press the oscillograph starting switch. At six engage the striking pins by sharply moving the flywheel to the right. This must be a quick decisive motion. On the count of seven release the oscillograph switch.
4. Examine the record and make necessary calculations by referring to the curve of Fig. 8.

Conclusion

A new kind of torsional impact test has been devised which employs a simply made vee notch specimen with a theoretically zero gage length. A machine has been designed and constructed to test this specimen. It measures energy absorption and torque loads required in fracturing the test piece and records these values for study and future reference. Successful use has been made of existing strain analysing and DC amplifying equipment in these measurements.

A synchronizing device and a photo electric tachometer have been successfully designed as integral parts of the system, allowing energy measurements without mechanical connection to the flywheel. The machine has been designed with a certain flexibility in that a larger capacity may easily be obtained by substituting a bigger flywheel for the existing one.

Further analysis of test results can be made and information from additional specimens can be found in subsequent tests since the machine is now available for such work.

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