Part III. (2) The Sensitiveness of Initiators to Friction. Apparatus for Measuring Relative Sensitiveness to Grazing Friction with or without Grit

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Thus, if the ordinates are as follows,

height of fall (cm.) ...	50	100	150	200	250	300
percentage detonation (from gas evolved/maximum gas obtainable)	p_1	p_2	p_3	p_4	p_5	100

the area from which the insensitiveness is calculated is

$$A = 12{,}000 - \left(\frac{p_1}{2} + \frac{p_1+p_2}{2} + \frac{p_2+p_3}{2} + \frac{p_3+p_4}{2} + \frac{p_4+p_5}{2} + \frac{p_5+100}{2}\right) 20$$
$$= 11{,}000 - 20\,\Sigma_1^5 p.$$

The probable error in such a calculated area is

$$\overline{\Delta A} = -20\overline{\Delta \Sigma_1^5 p}.$$

(In grit sensitiveness determinations, the above remarks apply directly to the P.S.G. values. As previously explained, P.I.G. figures are obtained by calculating the percentage increase of initiations. This does not affect the probability argument.)

With the data available from the experiments reported, it can be tested how far the deviation in experimentally observed areas can be ascribed to chance errors within a single determination of F.I., and how far systematic variations such as changes from one anvil to another can affect the sensitiveness.

Within any one series of impact tests, systematic variations such as anvil hardness may be assumed constant, so that only random errors need be considered.

Random errors at any one impact height will be given by the mean value of Δp, where

$$\Delta p = \frac{\text{c.c. gas/cap} - \text{average c.c./cap}}{\text{maximum c.c./cap}} \times 100$$

and according to probability rules the probable error in $(\Delta p)_{\text{mean}}$ will be $\dfrac{0{\cdot}85\,|\,\overline{\Delta p}\,|}{\sqrt{n}}$, where n is the number of determinations.

(2) THE SENSITIVENESS OF INITIATORS TO FRICTION. APPARATUS FOR MEASURING RELATIVE SENSITIVENESS TO GRAZING FRICTION WITH OR WITHOUT GRIT

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[Plates 6 and 7]

Apparatus is described for subjecting explosive compositions to grazing friction between surfaces of various materials, which can be made to move at various relative velocities up to about 15 ft./sec. Conditions for obtaining reproducible results are detailed.

Tests on a number of initiators by means of this apparatus give an order of relative sensitiveness to rubbing between smooth surfaces of steel. When the rubbing occurs in the presence of grit, it is found that certain initiators such as lead azide and lead styphnate have their sensitiveness notably enhanced compared with others, such as mercury fulminate.

Photomicrographs of the explosives after rubbing show very considerable break-up of the crystals even when no detonation has occurred.

Introduction

Various methods proposed for comparing the sensitiveness of explosives to friction involve a blow which includes impact as well as sliding friction. A typical example is the I.C.I. sliding torpedo test, in which a metal weight slides down an inclined plane and strikes a layer of explosive at the end of its travel.

For purposes of research and development, it is important to segregate the results of different kinds of mechanical action on explosives. The friction machine now developed with this in view is based on an earlier Research Department friction machine, and introduces various refinements. Essentially, the explosive is supported on one surface, and is subjected to the grazing friction from a swinging pendulum, the base of which forms the second surface. The velocity of this second surface can be varied between 5 and 14 ft./sec., and the pressure between the surfaces can also be varied from 1 to 40 lb. total thrust. With these velocities and pressures, satisfactory comparisons can be made between the friction sensitiveness of various initiators. The test is not intended for use with high explosives, which require more severe mechanical action. (From cinematographic measurements on the boxwood mallet test for high explosives, up to 50 ft./sec. would be required. A pendulum 2 ft. long would only give $\frac{1}{3}$ of this velocity, as maximum.)

Description of the friction machine

In this machine the explosive is given a glancing blow from the end of a swinging pendulum. Figure 34, plate 6, shows the general arrangement. The pendulum is supported in a double *A* frame by ball races, adjusted so that it can swing freely in a vertical plane, and has no up and down movement at the bearings. The lower end of the pendulum is threaded into a shoe and can be locked in position by a lock nut. This permits the effective length of the pendulum to be varied. A circular wheel is clamped to the shoe by means of a central spindle.

Any one of the various surfaces to be tested with the explosives can be fixed to the surface of this wheel. It is locked in position by the central spindle during a test, and can be turned through any angle so as to expose fresh portions of the surface.

The initial angle of swing of the pendulum, to give various striking velocities when the wheel passes over the explosive, is marked on two curved metal guides. These guides, and the electromagnet which holds the pendulum at the initial angle, can be seen in figure 34. The electromagnet is operated by a foot switch (car type).

The stationary friction surface is carried by a tilting table at the base of the machine (cf. figures 35 and 36, plate 6). This table is balanced on a hardened steel knife edge. Its angle of tilt can be accurately adjusted by the screw and lock nut which bear on the steel base plate of the machine (see left of figure 35). Various weights can be placed on a scale pan below the steel base plate of the machine; this pan is attached to the tilting table by a steel rod. The function of these weights is to adjust the total upward thrust of the tilting table on the wheel of the pendulum, so as to vary the frictional drag.

Brass clamps seen in figures 35 and 36 are used to clamp the stationary friction surface to the tilting table. The surface shown in the photographs is emery paper, but steel, ebonite, or various factory materials can readily be adapted for this test.

A small plate of perspex attached to the rear clamp (e.g. figure 35) is used for adjusting the initial point of contact of wheel and stationary friction surface.

A semicircular scale at the top of the *A* frame (figure 34) can be used for determining the initial and final angles the pendulum makes with the vertical. Light spring indicators, one of which can be seen on the right of the scale in figure 34, are pushed to the extremes of the swing by the pendulum rod.

Most initiators are metal salts, which give off noxious fumes on detonation. To carry off these fumes a suction chamber is used, fitted with easily cleaned baffle plates, to catch the explosive when no detonation occurs. These baffle plates must be cleaned in destroying solution after every ten non-firing strokes, or thereabouts, to avoid the accumulation of dangerous quantities of initiator which might later cause a back-fire.

Standardization of working conditions

The following conditions have to be standardized to give reproducible results, for use in routine testing:

(1) Length of striking path of pendulum wheel on the tilting table.
(2) Angle of tilt of the table.
(3) Position of layer of initiator in relation to the first point of contact between wheel and table.
(4) Evenness of strike of wheel on stationary surface.
(5) Load on table.
(6) Initial angle of swing of the pendulum.
(7) Nature of friction surfaces used.
(8) Quantity of explosive used.

The following points may be noted in connexion with these working conditions.

(1) *Standardization of length of strike*

The length of strike depends on the tilt of the table, and also on the length of the pendulum, which determines the first point of contact between wheel and table.

Since it has been found that a long strike gives a greater percentage of ignitions, careful control of these conditions is important. This is done with the aid of fiducial lines on the perspex plate.

One line on this plate coincides with a mark on the pendulum shoe, when this is vertical. A second line was made on the plate $\frac{3}{8}$ in. away to the left of the first. The tilt of the table is now altered by adjusting the bearing screw, until on swinging the pendulum a few degrees, it comes to rest with its mark coinciding with this second line. In this way the initial point of contact is standardized $\frac{3}{8}$ in. from the centre line.

Tests showed that under these conditions the length of strike was between 0·6 and 0·7 in. at both 8 and 13 ft./sec. With a longer strike Service azide gave 100 % detonation over the whole range of striking velocities, and with a 0·4 in. stroke the less sensitive initiators failed to detonate.

(2) *Angle of tilt of the table*

This was approximately 1°, and was adjusted with the table initially horizontal (spirit level) by means of the bearing screw, by giving it two complete turns. When the table was horizontal, the less sensitive initiators failed to detonate.

(3) *Position of explosive on stationary friction surface*

In order to subject the explosive as far as possible to grazing friction only, it is set back approximately $\frac{1}{8}$ in. from the first point of contact of the wheel with the tilting table. This is done by using a T-shaped template to keep explosive away from the first $\frac{1}{8}$ in. during deposition on the rest of the surface (figures 35 and 36).

(4) *Evenness of strike of moving and stationary friction surfaces*

It is essential that the strike of the wheel should be even, as recorded by the parallel traces of initiator on the wheel after a swing. Wheels which do not give parallel traces give inconsistent results, due to irregularities of pressure, and also to poor pick-up and partial detonation with compounds such as L.D.N.R.

Boxwood wheels were found to warp, but mild steel wheels have proved satisfactory over a great number of tests. When emery paper or other surfaces are used, strips are cut to fit the circumference of the wheels, and are glued to it. The emery on these strips is then protected with strips of filter paper and brass, and the whole is held with a circular clamp. The turnbuckles joined by catgut are used to tighten up the quadrants of the clamp, and the whole is dried for 1 hr. at 50° C and cooled in a desiccator. With other surfaces, materials available in thin layers can be fixed in a similar way. Special means must be used in other cases to provide fixed and moving surfaces.

(5) *Load on table*

Cast lead weights are used to apply various loads, up to 40 lb. weight. With the tilting table used, a load of 1 lb. was required to give balance. (The point of suspension of the load is on the opposite side of the knife edge to the mid-point of the striking path of the wheel, and approximately equidistant from it. Thus the effective total load is the applied weight, less 1 lb.)

(6) *Initial angle of pendulum*

Various angles are calculated from observations on the time of swing of the pendulum, so as to give velocities at the lowest point increasing by intervals of 1 ft./sec.

(7) *Nature of the friction surfaces used*

With emery paper surfaces, it was found that if the grit was too fine, extreme mechanical action was required for detonation to occur. Oakey's no. 0 special blue emery paper was found to be sufficiently coarse to give data with a range of initiators of different sensitiveness. Coarser papers offered no advantage.

With steel surfaces, a mild steel wheel and a hardened steel strip on the tilting table gave satisfactory relative measurements, though it was found necessary to roughen the hardened steel in some cases, so as to hold the composition. Other surfaces used include aluminium, brass, ebonite, various bakelites, conducting rubber and boxwood. The purpose of these tests was usually to eliminate various possibilities of factory accidents, and the results are not suitable for quantitative comparison.

(8) *Quantity of explosive used for test*

It may be anticipated that the thickness of the layer of the explosive on the stationary friction surface will affect the percentage of ignitions for any one striking velocity. With emery paper surfaces, the explosive can be transferred in reproducible amounts by means of a small felt pad glued to a wooden handle (cf. figure 35). This was dipped into the initiator and then pressed down on to the emery strip. After removing the pad, a thin layer of initiator remained on the emery. The average weight of a layer depends on the initiator used, and fluffiness of the felt. It ranges from 10 to 20 mg. of explosive.

With other surfaces, it is necessary to transfer separately weighed quantities of explosives to the friction surface for each test and to sprinkle them on with a sieve. Weighing can readily be done using a paper balance, as described in part III (3).

(9) *Figures for friction sensitiveness based on a standard procedure*

A number of routine tests for sensitiveness have been specified, in which the results can be expressed in terms of standard figures. For some purposes it is highly desirable to express the friction sensitiveness of any particular composition in terms of a standard figure, so as to permit rapid comparison with other explosives. With the amount of information as yet available, it would be premature to specify any one routine method, to the exclusion of others.

Useful results have nevertheless been obtained using what may be called the 'Emery Paper Figure' (E.P.F.) for friction sensitiveness.

After drying, wheels and strips of emery paper ($10 \times 1\frac{1}{2}$ in.) are stored in a desiccator over calcium chloride until required. A load of 6 lb. is suspended from the table. The angle of the table is adjusted, a strip of the emery clamped to it and the wheel bolted on to the pendulum. The mark on the pendulum shoe is carefully lined up with the mark on the perspex window, as a small error makes a great difference to the result. The pendulum is swung back and allowed to rest on a safety bar which passes through the *A* frame.

The layer of initiator under test is placed on the emery surface as explained above. With the pendulum held in position by the magnet the rest bar is removed, the suction pump switched on and the scale indicator moved down so that it would come into contact with the pendulum arm after strike.

On releasing the pendulum, it gives the layer of initiator a glancing blow, and continues its swing freely to its highest point, which is marked by the scale indicator. The pendulum is caught by hand before it can pass over the table on its return journey. The table is depressed by hand, the gate opened and the pendulum swung to the left-hand side of the *A* frame. If firing does not occur, the initiator is brushed off the paper into the chute of the fume extractor. The emery surface on the wheel is renewed by unclamping the wheel, turning it round a few degrees then reclamping; the surface on the table is renewed by loosening the clamp screws, moving the strip along about 1 in. and then tightening the clamp screws. The procedure is repeated ten times for each of the ten different velocities within the range of the machine, i.e. from 5 to 14 ft./sec. at increments of 1 ft./sec. This range of velocities adequately covers the sensitiveness of all the initiators tried, giving a representative number of firings. Each wheel can be used for about twenty strikes. After use the wheels and strips of emery from the table are placed in water, destroying solution is poured in to remove any initiators and the wheels are subsequently removed and cleaned ready for future use.

Table 39 shows the method of setting out a typical determination. The order of the tests was arbitrary and it was convenient in the example (table 39) to start at 11 ft./sec. at which velocity seven firings were obtained. The tests were then done at the higher velocities until ten firings were given, and at the lower velocities in order until ten failures were obtained. Firing of the initiator is indicated in table 39 by *G* and a failure by *N*. The number of firings in brackets are the assumed values for the velocities not tested; experiment has shown that this assumption is justified. The angle to which the pendulum rises after each strike is noted.

The percentage firing is computed by the addition of the number of firings over the range of the ten velocities. The results for the various initiators are tabulated in tables 40 and 41.

TABLE 39. LAYOUT OF A DETERMINATION OF EMERY PAPER FIGURE

Initiator: Mercury fulminate. Surfaces Oakey's 0. Load 6 lb.

final angle	32	31	32	32	31	31	31	31	31	32	velocity 7 ft./sec.
firing	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	firing 0/10
final angle	37	37	38	37	37	37	37	37	37	37	velocity 8 ft./sec.
firing	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*G*	*N*	*N*	firing 1/10
final angle	41	41	41	42	41	41	42	41	41	41	velocity 9 ft./sec.
firing	*N*	*G*	*N*	*N*	*N*	*N*	*G*	*G*	*N*	*G*	firing 4/10
final angle	47	47	47	47	47	47	47	47	48	47	velocity 10 ft./sec.
firing	*N*	*G*	*G*	*N*	*G*	*N*	*N*	*G*	*N*	*N*	firing 4/10
final angle	53	53	53	53	53	53	54	53	53	53	velocity 11 ft./sec.
firing	*N*	*G*	*G*	*G*	*G*	*G*	*N*	*G*	*N*	*G*	firing 7/10
final angle	61	60	60	60	60	61	60	60	61	61	velocity 12 ft./sec.
firing	*N*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	firing 9/10
final angle	66	66	66	66	66	66	66	65	65	66	velocity 13 ft./sec.
firing	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*G*	firing 10/10

Result

velocity (ft./sec.)	5	6	7	8	9	10	11	12	13	14	
firings/10	(0)	(0)	0	1	4	4	7	9	10	(10)	% firing 45

TABLE 40. SUMMARY OF EMERY PAPER FIGURES

Surfaces Oakey's no. 0 Emery Paper. Dead load on table 6 lb.

	firings in 10 at the following ft./sec.										% firing
initiator	5	6	7	8	9	10	11	12	13	14	E.P.F.
Service azide	4	4	9	10	(10)	(10)	(10)	(10)	(10)	(10)	87
664	6	4	8	7	9	10	10	(10)	(10)	(10)	84
Q.F. composition	3	3	4	9	10	(10)	(10)	(10)	(10)	(10)	79
mercury fulminate	(0)	(0)	0	1	4	4	7	9	10	(10)	45
basic L.D.N.R.	(0)	(0)	(0)	0	1	5	7	5	9	9	36
dextrin azide	(0)	(0)	(0)	(0)	0	1	1	5	6	10	23
lead styphnate	(0)	(0)	(0)	(0)	0	1	1	5	5	9	21

Note. Q.F. composition consists of glass powder, antimony sulphide and potassium chlorate.

Results listed in table 40 give a picture of the relative sensitiveness of various initiators, under conditions of grit friction. The effect of the rubbing can be seen from photographs of Service and dextrin azide before and after strike, when no detonation took place (velocity 6 ft./sec. in case of Service azide, and 13 ft./sec. with dextrin azide). Crystals of Service azide are seen to be broken up, and inspection under the polarizing microscope shows that some emery grit is rubbed off the paper and mixed with the fragments (figures 37 to 42, plate 7).

Experiments with smooth steel surfaces gave different order of sensitiveness of some of these compositions, as can be seen from table 41.

TABLE 41. STEEL ON STEEL FRICTION SENSITIVENESS

6 lb. load, mild steel wheel, hard steel plate on tilting table

initiator	striking velocity (ft./sec.) 5	6	7	8	9	10	11	12	13	14	% firing
664	2	4	8	10	(10)	(10)	(10)	(10)	(10)	(10)	84
basic L.D.N.R.	0	3	5	8	10	(10)	(10)	(10)	(10)	(10)	76
mercury fulminate	(0)	(0)	1	5	8	8	7	9	10	10	58
Q.F. composition	no firings										0
lead styphnate	do.										0
Service azide	do.										0
dextrin azide	do.										0

Substantially the same results are obtained with a dead load of 40 lb. instead of 6 lb. on the tilting table.

DISCUSSION

The main conclusion to be derived from comparing these data with the E.P.F. is that certain initiators are markedly sensitive to grit friction, as distinct from the sliding friction between crystals of the explosive, or between surfaces of steel.

This marked grit sensitiveness is of practical importance, since it contributes to some of the risks in filling shops. Detailed interpretation of the results is, however, hampered by the uncertain mechanical nature of grit friction from emery paper, on account of its paper and glue backing. Preliminary experiments carried out with the friction machine, using steel on steel, and mixing particles of grit with the initiator, confirm that certain initiators are specially grit sensitive.

In impact tests, a large proportion of the energy is dissipated in the explosive, since the impact is necessarily inelastic. On the other hand, if a large proportion of the kinetic energy of the pendulum were dissipated in the friction test, the comparison between different explosives might be vitiated by unequal losses of velocity during the rubbing process.

Estimates of the energy loss can readily be made by comparing the initial angle of swing of the pendulum, with the angle to which it rises after rubbing the tilting table.

Allowance for energy losses at the roller bearing can be made from swing measurements with the tilting table removed.

Typical observations derived from a large number of determinations are given in table 42.

In general, the percentage loss in velocity is not sufficient to give rise to serious variations with different initiators. Direct comparisons with and without initiator show that the layer of explosive makes little difference to the velocity loss, for emery paper on steel, and actually acts as a lubricant in the case of steel on steel, as table 43 shows.

Table 42. Emery paper on steel, load 6 lb.

velocity (ft./sec.)	5	6	7	8	9	10	11	12	13	14
initial angle (degrees from the vertical)	29	35	41	47	53	59	66	73	80	88
final angle (free swing)	27	32	38·5	44	49·5	55·5	62·5	69·5	75·5	84
final angle (rubbing friction)	20	25	32	37	41	47	53	60	66	75
percentage loss of velocity due to rubbing	—	10·0	16·6	14·7	17·6	16·6	14·6	12·0	12·0	10·0
actual energy loss at the rubbing surface (ft./lb.)	0·25	0·3	0·33	0·4	0·53	0·59	0·71	0·76	0·8	0·77

Table 43. Mild steel wheels, hard steel stationary surface

	ft./lb.
using 6 lb. load, average energy loss with explosive	0·15
using 6 lb. load, average energy loss in absence of explosive	0·28
using 40 lb. load, average energy loss with explosive	0·3
using 40 lb. load, average energy loss in absence of explosive	0·5

(3) THE SENSITIVENESS OF INITIATORS TO FRICTION. TEMPERATURE COEFFICIENT

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[Plate 8]

In part III (2), a machine was described for subjecting explosives to grazing friction between a stationary and a moving surface, rubbing one over the other. By arranging Service initiators in a scale of increasing sensitiveness, it was shown that a different order was obtained: (*a*) when the rubbing surfaces were coated with standard emery paper, so that the friction was due to particles of hard grit; (*b*) when the rubbing surfaces were of steel; (*c*) when grit was introduced between steel surfaces.

Initiators such as mercury fulminate show much the same sensitiveness in all three cases, but others, such as Service azide, are notably more sensitive under the action of grit. The experiments described in this section were designed to give additional information on the nature of grit sensitiveness in particular, by investigating: (1) the effect of raising the temperature of the rubbing surfaces; (2) the deadening produced by wetting the explosive with various liquids.

The relative probability of initiation by grazing friction was determined for a range of velocities of the rubbing surface, as described in the part quoted above. Principal changes in determining grit sensitiveness were:

(i) Graded emery powder was mixed with the initiator which was then rubbed between steel surfaces. One reason for eliminating the use of paper was the uncertainty arising from the effect of heating or wetting on the standard emery paper.

(ii) An initiator balance (described below) was used to weigh out standard quantities of compositions for each test. These were sprinkled over a constant area of the steel on the tilting table through a small multiple sieve.

(iii) The temperature of the tilting table, and of the thin layer of powder on it was maintained by electric heaters, at various temperatures up to 300° C.

(iv) To investigate the deadening effect of liquids, drops or a fine spray were applied to the layer of composition. Liquids used included water and glycerine solutions with and without the addition of capillary active substances, and ethyl and butyl alcohols.