THE INSTRUMENTATION OF A ROTARY TABLET MACHINE

BY E. SHOTTON, J. J. DEER AND D. GANDERTON

From the Department of Pharmacy, School of Pharmacy, Brunswick Square, London, W.C.1

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A rotary tablet machine has been instrumented to measure the forces operating during the compression cycle. A radio link was used to transmit to a recording unit the effect of pressure on strain gauges attached to the punches. Sodium chloride and aspirin were compressed at various pressures and the results compared, using strength and porosity data, with tablets of the same materials prepared on an eccentric machine.

THE use of small-resistance strain gauges bonded to the punches or the frame of a single punch, eccentric tablet machine has allowed accurate measurement of the forces exerted by the upper punch and transmitted to the lower punch (Higuchi, Nelson and Busse, 1954; Hasegawa, 1959; Shotton and Ganderton, 1960; Riad and Zobel, 1962; Fuhrer, 1962). Such instrumentation has led to some success in the correlation of the forces of compression with various tablet properties, such as strength, disintegration, porosity, static electrification and weight variation. Since the eccentric machine has been almost completely replaced by the rotary tablet machine, it seemed desirable to compare the two types of machine and the effect of pressure being applied by the movement of both punches. Seth and Munzel (1958) attempted a comparison of tablets prepared on eccentric and rotary machines by compressing different portions of the same granulation to the same density on each machine. However, as the compressional forces were not determined, the comparison was incomplete.

This paper describes a rotary tablet machine instrumented to give simultaneous records of the pressure exerted by the upper and lower punches. Two crystalline materials, sodium chloride and aspirin, were compressed, the compression cycle was analysed, and the results compared, using crushing strength and porosity data, with compression on an eccentric machine.

The Instrumentation of a Rotary Tablet Machine

A 16-punch, rotary tablet machine (Manesty Machines Ltd. Type D.3) blanked off to leave one punch and die set was kindly made available by Burroughs Wellcome and Co. Ltd. of Dartford.

In an eccentric machine, strain gauges were mounted on the punches and the signals obtained by direct connection, but the movement of the turret of a rotary machine precludes the use of fixed leads. This problem offered two practicable alternatives: either the use of slip rings or radio telemetry. A slip ring system required such modification of the machine as to confine instrumentation to one particular machine. Also, electrical noise resulting from loose powder adhering to the slip rings could only be avoided by careful screening or the use of an enclosed ring, such as the mercury contact slip ring. For these reasons, the slip ring system was rejected in favour of radio telemetry.

Two strain gauges (H. Tinsley Co. Ltd. Type 6J. Gauge factor 2·19. Resistance 100 ohms) were bonded to the shank of a plane faced, half-inch punch and connected in series. A small terminal block was cemented between the gauges with "Araldite" and leads were attached. The strain gauges formed the active arm of a Wheatstone bridge. The other three arms, consisting of two matching strain gauges as a reference arm and two high stability 200 ohm carbon resistors, were mounted on a small plastic plate with an oscillator, amplifier and driving batteries. A variable resistance was fixed in parallel to the reference arm for balancing the bridge. The bridge was activated by an alternating current at approximately 7 V and about 550 c./sec. supplied by a small solid state oscillator (Telephone Manufacturing Co. Ltd. Type SO11). The bridge output was amplified (Telephone Manufacturing Co. Ltd. Solid state amplifier. Type SA 10) and the signal passed to the transmitter through the condensers C1 and C2 (Fig. 2).

The plate was fitted beneath the upper punch casting, with the amplifier and oscillator inserted into vacant punch holes, and held in position by screws, which passed through the casting and held a second plate in position on the top. This plate carried a calibrating resistance, which when connected across the active arm of the bridge by its associated switch, gave an out of balance of 0·15 per cent.

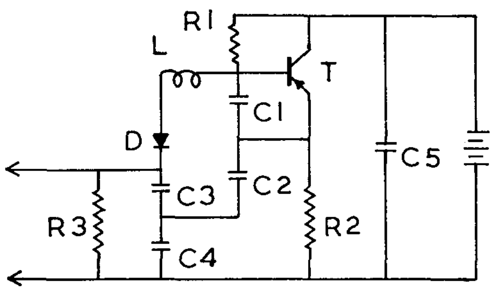

FIG. 1. Modified Gouriet Oscillator. R_1 50 kΩ. R_2 1 kΩ. R_3 100 kΩ. C1, C2 and C4 30 Pf. C3 and C5 1000 Pf. T Transistor OC171 (Mullard). D Diode OAZD (Mullard). L Coil. Two turns 0·5 in. diameter. 20 S.W.G. copper wire.

The transmitter circuit was similar to that described by Wolff, McCall and Baker (1962). The circuit, shown in Fig. 1, was modified for use with a standard domestic tuning unit, operating in the region of 100 Mc./sec. The transmitter was encapsulated in "Araldite" and this and its driving batteries were housed in adjacent punch holes. In this way a compact system was constructed which cleared the stationary feed frame. A block diagram of the transmitting apparatus is given in Fig. 2.

The receiving apparatus consisted of a tuning unit (H. J. Leak Co. Ltd. Type Troughline II), the output of which was modified by a full wave rectifier bridge. The output was fed into a recorder (New Electronic

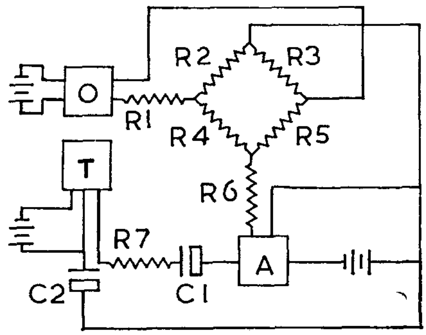

FIG. 2. Block diagram of complete transmitting apparatus. R1, R2, R3, R4 and R5 200 Ω. R6 1 kΩ. R7 2 kΩ. Cl and C2 4 μF (electrolytic). O Oscillator. T Transmitter. A Amplifier. Voltages. O 8 V. T 6·5 V. A 8 V.

Products. Ultra-violet Recorder Type 1050) using resistors to comply with the impedance of the components. The galvanometers used with the recorder had a natural frequency of 100 c./sec. (Southern Measuring Instruments. Type SMI V). A block diagram of the receiving circuit is given in Fig. 3.

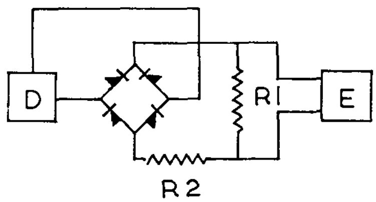

FIG. 3. Block diagram of receiving apparatus. D Tuner. E Recorder. R1 250 Ω. R2 10 kΩ. Bridge 4 × OA10 Diode. (Mullard.)

A similar bottom punch system, differing only in the spatial layout of the components, was constructed and fitted beneath the die-plate of the tablet machine. The transmitter occupied a vacant die space. Since the passage of the metal feed frame over the transmitter severely modulated the frequency, the transmitter was so placed to be clear of the feed frame during the compression cycle.

A dipole aerial, shaped to follow the circumference of the die-plate and having an uninterrupted view of the radiating coils of both transmitters was fixed to the machine.

In order to record simultaneously the upper and lower punch forces, the components of the transmitters were so chosen to give a basic frequency of 104 Mc./sec. for the upper punch transmitter and 96 Mc./sec. for the lower punch transmitter. Thus, by suitable tuning of the receiving units, complete separation of the two signals was obtained.

The punches were calibrated separately by mounting them on a standardised strain column and compressing the assembly between the platens of a small hydraulic press. After the construction of force-deflexion series from 0–3,000 kg., the load was released and an out-of-balance of 0·15 per cent was introduced into the punch bridge circuit by switching a suitable resistance into parallel with the active arm of the bridge. The associated deflexion was recorded and evaluated in terms of force. Thus, the deflexions recorded during the compression of a tablet could be evaluated by comparison with the switched out-of-balance deflexion.

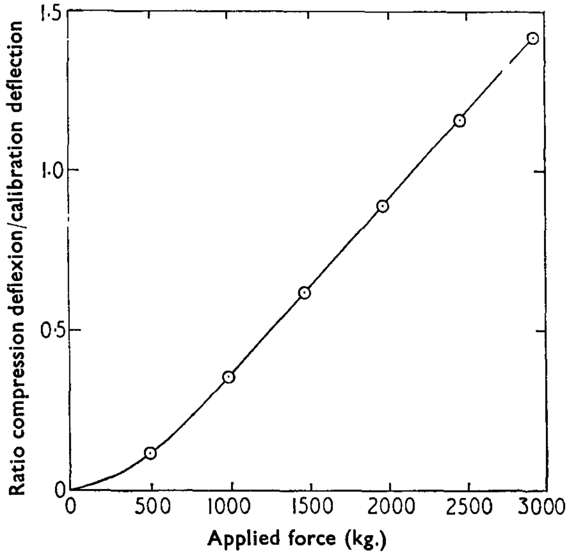

FIG. 4. The upper punch calibration curve.

The relation between galvanometer deflexion and applied load is given in Fig. 4. This relation is linear over the force range 800–3,000 kg. but shows curvature to the origin below 800 kg. The experimental work was confined to this range with two exceptions when forces just below 800 kg. were recorded. The calibration deflexion was reproducible and gave values of 2,080 $\pm$ 60 kg. for the upper punch and 1,930 $\pm$ 30 kg. for the lower punch in eight independent trials.

Aspirin and sodium chloride were selected for the initial study because their compression properties have been extensively studied with an eccentric machine. Aspirin is easily compressed to a low porosity, whereas sodium chloride shows considerable resistance to consolidation. When compressed on an eccentric machine, both materials give high die wall friction effects resulting in marked differences between the upper and lower punch forces. Both, however, can be satisfactorily compressed without the aid of lubricants.

EXPERIMENTAL

Sodium chloride and aspirin were sieved and 30–40 mesh fractions of each material were selected. For most of the work, the feed frame was not used. Weighed samples of the material were fed into the die by hand with the die-place diametrically opposite the compression point. This procedure was adopted so that the recording system could be calibrated immediately before or after compression.

The weight of the samples was chosen to give a tablet 0·4 cm. thick at zero porosity. Six or eight tablets were prepared at each pressure level and the pressure range 600–2,000 kg./cm.^{2} was investigated at seven or eight points. To reduce systematic errors, intermediate pressures were first investigated. Compression at high pressures was followed by a low pressure study, with the production of tablets at the original machine setting as a check. The tablets were collected and stored in closed containers for 6 hr. They were then weighed, the thickness and diameter measured, and the strength estimated using a crushing test previously described by Shotton and Ganderton (1960). The duration of the compression cycle was evaluated from the galvanometer records.

The feed frame was fitted to the machine for the production of aspirin tablets over the same pressure range. The weight, thickness, strength and duration of compression cycle were evaluated as before.

Finally, for comparison with the tablets produced on the rotary tablet machine, the same samples of aspirin and sodium chloride were compressed on an eccentric machine using direct leads.

As the projection of the linear portion of the graph showing the relation between applied load and galvanometer deflexion did not pass through the origin a graphical correction was made for computing the load.

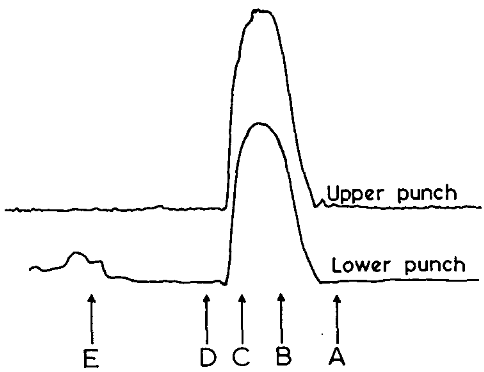

FIG. 5. Record of the compression of a tablet of sodium chloride. See text for explanation of symbols.

Details of Compression Cycle

Fig. 5 is an example of the traces obtained from the upper and lower punch of the rotary tablet machine during the compression cycle. The upper punch after moving down its guide, rests on the powder in the die, meets the pressure-wheel at position A and is forced downwards under the pressure wheel, to position B when the leading edge of the flat punch top reaches bottom dead centre. The flat punch top passes under bottom dead centre and position C represents the point at which the flat punch top leaves bottom dead centre. At position D, the punch leaves the pressure-wheel and position E represents the ejection of the tablet. These approximate punch positions were obtained visually by rotating the machine by hand.

The force exerted by the pressure wheel at positions B and C is less than that exerted when the centre of the punch passes bottom dead centre as the force at B and C will be exerted at an angle to the vertical and only the vertical component will be measured at the punch tip.

RESULTS

From the paper speed of the recorder the approximate duration of the compression cycle was found to be 0·16 sec. for all tablets produced on the rotary tablet machine. For the eccentric machine, the duration was about 0·14 sec. for aspirin and about 0·11 sec. for sodium chloride, these values being variable due to turning the machine by hand.

The results for sodium chloride compressed on both rotary and eccentric machines are summarised in Table I. The results for aspirin are given in

TABLE I

THE COMPRESSION OF SODIUM CHLORIDE

Upper punch pressure Pa, kg./cm.²	Lower punch pressure Pb, kg./cm.²	Mean compaction pressure Pm, kg./cm.²	$\frac{Pb}{Pa}$	Weight of tablet, g.	Porosity, per cent	Crushing strength Fc, kg.
			Rotary tablet machine			
2,190	1,980	2,090	0·90	1·0957	4·7	22·9
1,990	1,810	1,900	0·91	1·0970	5·5	23·7
1,740	1,560	1,650	0·90	1·0961	7·0	18·7
1,550	1,400	1,480	0·90	1·0960	8·0	15·8
1,370	1,230	1,300	0·90	1·0956	9·7	15·0
1,070	1,000	1,040	0·94	1·0933	13·1	11·1
820	760	790	0·92	1·0940	17·2	7·5
630	550	590	0·88	1·0919	21·2	5·5
			Eccentric machine			
1,970	1,390	1,680	0·70	1·0884	6·1	13·7
1,570	1,170	1,370	0·74	1·0921	8·3	12·9
1,300	960	1,130	0·74	1·0913	10·8	10·2
990	760	880	0·77	1·0942	14·0	6·8
550	430	490	0·78	1·0902	21·5	3·7

All values are the mean of six results

TABLE II

THE COMPRESSION OF ASPIRIN

Upper punch pressure Pa, kg./cm.²	Lower punch pressure Pb, kg./cm.²	Mean compaction pressure, kg./cm.²	$\frac{Pb}{Pa}$	Weight of tablet, g.	Porosity p, per cent	Crushing strength Fc, kg.
			Rotary tablet machine			
2,080	1,860	1,970	0·89	0·7182	4·7	5·7
1,720	1,510	1,620	0·88	0·7191	5·3	5·6
1,520	1,340	1,430	0·89	0·7181	5·5	5·0
1,350	1,190	1,270	0·88	0·7172	5·9	4·6
1,080	950	1,020	0·88	0·7114	6·8	3·8
820	740	780	0·89	0·7117	7·4	3·3
650	580	620	0·89	0·7166	7·6	2·7
			Eccentric tablet machine			
2,370	1,780	2,080	0·75	0·7202	4·7	6·1
2,140	1,560	1,850	0·73	0·7211	4·7	5·9
1,860	1,310	1,590	0·71	0·7212	4·9	5·3
1,330	920	1,120	0·69	0·7210	5·4	4·5
820	550	690	0·67	0·7185	6·5	3·6

All values are the mean of six results

Table II and the results obtained by frame feeding aspirin to a rotary machine are given in Table III.

TABLE III

THE COMPRESSION OF ASPIRIN ON A ROTARY TABLET MACHINE USING A FEED FRAME

Upper punch pressure Pa, kg./cm.²	Lower punch pressure Pb, kg./cm.²	Mean compaction pressure Pm, kg./cm.²	Pb/Pa	Weight of tablet, g.	Porosity p, per cent	Crushing strength Fc, kg.
2,160	1,920	2,040	0·89	0·7165	5·5	5·1
1,740	1,380	1,560	0·79	0·7138	5·9	4·5
1,400	1,160	1,280	0·83	0·7117	6·3	3·6
960	820	890	0·85	0·7223	6·8	3·1
810	730	770	0·90	0·7051	7·0	2·6
680	590	640	0·87	0·7242	7·7	2·3

All values are the mean of 10 results

The results obtained from hand feeding and compressing aspirin and sodium chloride on the two machines were compared using the relation between porosity and mean compaction pressure (Fig. 6) and between crushing strength and mean compaction pressure (Fig. 7).

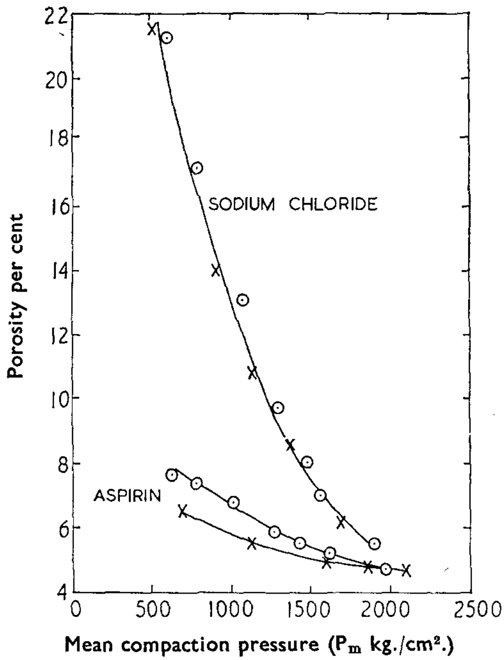

FIG. 6. Relation between porosity and mean compaction pressure for tablets of aspirin and sodium chloride. × Results from the eccentric machine, ⊙ Results from the rotary machine.

DISCUSSION

The results given in Tables I and II indicate that the ratio between the lower punch pressure and the upper punch pressure, P_b/P_a, during compression on a rotary machine was greater than during compression on an

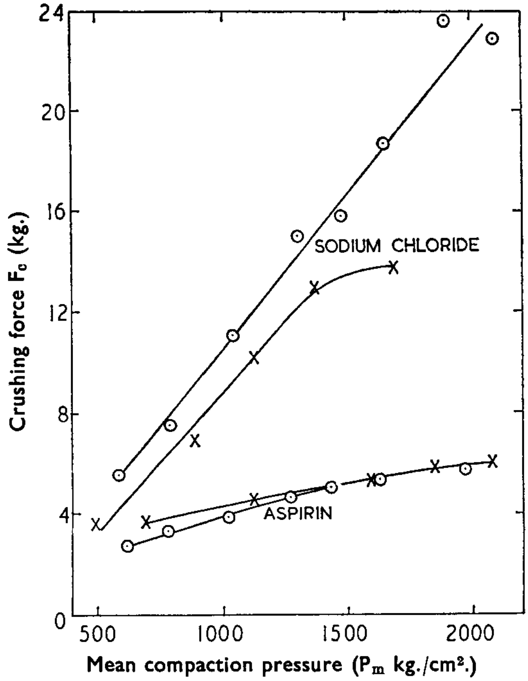

FIG. 7. Relation between crushing force and mean compaction pressure for tablets of aspirin and sodium chloride. × Results from the eccentric machine, ⊙ Results from the rotary machine.

eccentric machine. This is to be expected from the comparison of a compression cycle in which both punches move with a cycle in which the lower punch remains stationary. An average value $P_b/P_a = 0{\cdot}91$ was given during the compression of sodium chloride on a rotary machine. This value remained constant throughout the pressure range under study. On an eccentric machine the ratio P_b/P_a fell from 0·78 to 0·70 as the pressure range was ascended. Similar results were obtained from the compression of aspirin. The punch pressure ratio was slightly lower on both machines, showing a constant value of about 0·89 on the rotary machine and varying from 0·67 to 0·75 on the eccentric machine.

Some of the differences between the value of Pb/Pa for the two machines could be accounted for by difference in die wall polish and in the clearance between punches and die. We think, however, that this effect may be small compared to the effects derived from the different punch movements of the two machines.

Since the upper and lower punch forces recorded on the rotary machine are unequal, the system must be balanced by a force at the die wall acting in an upwards direction and derived from the frictional reaction to a slight downward movement of the tablet during compression. The explanation of this movement was found in the mounting of the lower punch pressure wheel which is depressed during compression, extending an overload spring through a series of levers. Essentially, the tablet is being compressed between a rigid upper punch and a sprung lower punch.

The consolidation of the materials with increasing pressure is given in Fig. 6. The relation for sodium chloride is almost the same for both rotary and eccentric machines. Thus, the overall density achieved during compression is largely unaffected by the difference in the duration of compression and the inequality of the forces exerted by the upper and lower punches. Aspirin, on the other hand, yielded tablets of lower porosity on the eccentric machine. The difference diminished with increasing pressure and finally disappeared at the highest pressures studied.

Tablets of sodium chloride produced on the rotary machine gave a higher crushing strength than tablets produced at the same pressure on the eccentric machine. The higher strength, as evaluated by the crushing test, may be due to the variation in porosity and therefore strength between the upper and lower parts of the tablet. In tablets produced on an eccentric machine, the porosity and strength will vary markedly in different parts of the tablet because of large differences in the upper and lower punch pressures. It is possible that fracture could be initiated at a lower crushing force, finally indicating a strength which is lower than a tablet of the same density produced on a rotary tablet machine.

The strength of aspirin tablets produced on the two machines was the same at pressures above 1,500 kg./cm.^{2}. In this region a limiting porosity is approached and variations in density and strength in different parts of the tablet will probably be small. At lower pressures, tablets produced on the eccentric machine were slightly stronger. This is commensurate with the lower porosity of these tablets. Comparison of Fig. 6 and 7 show that as the pressure increases, differences in strength and of porosity disappear.

The results from experiments using the feed frame gave pressure ratios similar to the hand-fed series. The wider variation of these results was due to changes in the calibration deflexion during the production of a series of tablets. The lower strength of these tablets was probably due to the production of fine powder as the machine rotated, thus affecting the binding properties of the aspirin.

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The paper was presented by PROFESSOR SHOTTON.