Instrumented Rotary Tablet Machines I

Design, Construction, and Performance as Pharmaceutical Research and Development Tools

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Two conventional rotary tablet compressing machines, the Stokes models 540-35 and BB2-27, have been instrumented to measure both compressional and ejectional forces. This was accomplished by attaching strain gauges to key components of the presses and displaying the electrical outputs of the strain gauges on a dual-beam oscilloscope fitted with a camera. The compressional and ejectional forces developed during the tableting operation are thus obtained under dynamic conditions. The design, construction, and performance of these instrumented rotary tablet machines (IRTM) are described and illustrated.

ALTHOUGH COMPRESSED tablets have been in use for many years, fundamental research concerning tableting was initiated only little more than a decade ago. Since that time, attempts have been made to isolate and evaluate the effects of many of the variables involved in the complex process of producing a tablet. Some of the most significant information has been obtained with instrumented single punch tablet machines where the compressional and ejectional forces involved in the tableting operation could be accurately detected, recorded, measured and, if necessary, reproduced.

The instrumentation of single punch compressing machines was first described by Brake in 1951 (1) and later by Higuchi, Nelson, and Busse (2), Gagnon (3), Markowski (4), and most recently by Shotton and Ganderton (5).

By attaching strain gauges to the upper punch of a single stroke Colton 4B press,[1] Brake (1) was able to measure and record the compressional force exerted in the tableting process.

Higuchi and co-workers (2) modified a Stokes model A3 tablet machine[2] and attached strain gauges and load cells directly to the press. This instrumentation permitted the simultaneous recording of any two of the following variables as functions of compression time: (*a*) the absolute force exerted by the upper punch; (*b*) the absolute force transmitted to the lower punch; and (*c*) the absolute displacement of the upper punch. They were also able to determine the force of ejection.

Gagnon (3) attached strain gauges to the lower punch of the instrumented press used by Brake. This enabled Gagnon to detect and measure the lower punch compressional force. Markowski (4) further refined this system to measure the ejectional forces as well as upper and lower punch forces.

Shotton and Ganderton (5) attached strain gauges to the upper punch and lower punch holder of "a Lehman single punch eccentric tableting machine, driven at a constant speed through a Kopp Variator." They were able to measure the upper and lower punch compressional forces as well as the ejectional force.

The value of these instrumented single punch tablet machines in investigating fundamental aspects of tableting has been clearly established (1–21). However, single stroke machines are usually used only for research and pilot batches, for small volume production items, or for large size specialty tablets such as boluses. Today, rotary tablet machines are the conventional type of compressing equipment in the pharmaceutical industry. It was felt that methods were needed to measure and record the compressional and ejectional forces involved in the preparation of tablets on high speed rotary presses under production conditions.

This paper discusses the instrumentation of two widely used rotary tablet presses, a Stokes model 540-35 and a modified Stokes model BB2-27.[2] The instrumentation permits the simultaneous detection and recording of (*a*) the compressional forces during the formation of the tablets in their dies and (*b*) the ejectional forces during the removal of the tablets from their dies. This communication describes and illustrates the design, construction, and performance of these machines.

REQUIREMENTS OF DESIGN

In instrumenting rotary tablet machines, two distinct problems were encountered: (*a*) finding the means of detecting the compressional and ejectional forces and (*b*) finding an adequate method of moni-

Received May 16, 1963, from the operating units of Product Research and Development and Mechanical Engineering, The Upjohn Co., Kalamazoo, Mich.
Accepted for publication August 5, 1966.
Presented to the Scientific Section, A.PH.A., Miami Beach meeting, May 1963.
Instrumentation of rotary tablet machines is claimed in U.S. pat. 3,255,716 (June 14, 1966).
The authors acknowledge the technical assistance of Miss Jane Patterson, Mr. C. R. Hine, Mr. D. D. Noble, Mr. M. Flegal, and members of the Tablet Production Unit.
[1] Arthur Colton Co., Detroit, Mich.
[2] F. J. Stokes Corp., Philadelphia, Pa.

toring (*i.e.*, amplifying, displaying, recording, and measuring) the detected forces.

Force Detecting System.—To detect the forces, a system was required that: (*a*) could be readily attached to a conventional high speed rotary tablet press; (*b*) could operate over a wide range of thickness, die fill, overload, and speed settings; (*c*) would not interfere with the normal operations of the press; (*d*) would permit the detection of individual forces for each station; (*e*) would permit the use of any size or shape punches and dies; (*f*) could be readily transferred to other machines of the same type.

Commercially available strain gauges were selected as the force sensors. Because of the simplicity, sensitivity, reproducibility, reliability, versatility, durability, and short recovery time of strain gauges, the first three requirements were fulfilled.

It was obvious, however, that if the punches of each station were to be instrumented in a manner similar to that used to gauge the single punch machines, complex electronic arrangements would be required to "pick up" and transmit the impulses from each set of gauges. If some portion of the press remotely linked to the punches could be gauged to detect the desired forces as they occurred at each station, requirements (*d*) and (*e*) would be achieved. The last requirement would also be fulfilled if the members selected for gauging were conveniently transferable to another machine. Since cast iron and similar materials do not exhibit constant values of the modulus of elasticity[3] and Poisson's ratio,[4] the gauges would have to be attached to steel portions of the press.

Monitoring System.—To monitor the detected electrical impulses, a system was required that: (*a*) could follow at least two simultaneous or exceedingly rapid, consecutive events (*e.g.*, the compression and ejection events); (*b*) could respond to a tablet production rate of at least 2,000 tablets per minute (TPM); (*c*) would follow and record either individual or a consecutive series of compression and/or ejection events; (*d*) could respond to and measure compressional forces ranging from 200 to 10,000 lb.; (*e*) would be sensitive enough to amplify and measure the lower magnitude ejectional force impulses. As the ejectional forces are usually smaller than compressional forces, the electrical output of the gauges would be lower; (*f*) would allow some sort of permanent record to be readily obtained at any time if desired; (*g*) would be versatile, relatively easy to operate, and yet would not interfere with or limit the normal operation of the press; (*h*) would be stable, durable, portable, and self-contained (*i.e.*, not dependent upon a wide variety of associated equipment or procedures, such as photographic development, etc.).

The monitoring system meeting the above requirements consists of a high sensitivity dual-beam oscilloscope, such as a Tektronix model 502 fitted with a Tektronix model C-12 camera.[5] The camera, equipped with a $f/1.9$ lens having a 1 to .9 object-to-image ratio, is fitted with a Polaroid roll film back.

The electronic traces of two events can be displayed simultaneously on this oscilloscope. Each beam can be adjusted separately over a wide range of vertical sensitivity settings (20 v./cm. to 200 μv./cm.). Because the sweep range selection is large (5 sec./cm. to 1 μsec./cm.), either an individual or a series of impulses can be displayed. The persistency of the image on the screen is controlled by the intensity setting of the beam, and a green filter can be inserted to prolong the image. Impulse heights can be estimated directly from the graticule which is calibrated in 1-cm. divisions with 2-mm. markings at the baselines.

With the camera attached to the oscilloscope, a permanent record can be obtained at any time without interfering with the visual observation of the screen by taking a picture through the beam splitting mirror. The photographic prints, which are obtained in less than 30 sec., reproduce the graticule markings as well as the electronic traces to $^9/_{10}$ their original size. Fast speed film permits the capture of very rapidly occurring events or sequences with extremely good resolution. Film which produces high contrast transparencies can also be used.

Portability of the entire monitoring system is obtained by mounting the camera, oscilloscope, batteries, and Wheatstone bridge circuits on a wheeled cart (see Fig. 5).

INSTRUMENT DESIGN AND CONSTRUCTION

This phase of the investigation consisted of selecting the proper press components to be gauged, installing the gauges on the selected components, and confirming that the gauges were responsive to the stresses produced.

The Stokes model 540-35 was the first rotary press to be instrumented in our laboratory.

540-35 Press.—The essential features of the system to detect compressional forces for this press are shown in Fig. 1. The mechanical design of the press overload system is such that oil under preset pressure forces one end of a lever system against an adjustable stop screw. The opposite end of the lever supports the upper compression roll. As tablets are compressed, the force on the punches operates through

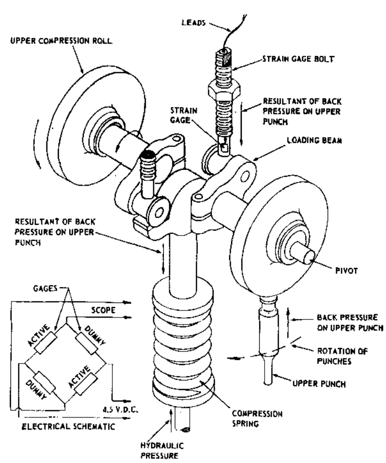

Fig. 1.—Instrumentation of 540-35 press. (Detection of compressional force.)

[3] Modulus of elasticity in compression is the constant which expresses the ratio of unit stress to unit deformation for all values of unit stress not exceeding the proportional limit of a material.
[4] Poisson's ratio, also known as the factor of lateral contraction, is the ratio of lateral unit deformation within the elastic limit.
[5] Tektronix, Inc., Beaverton, Oreg.

the upper compression roll and the lever to reduce the force applied to the adjusting screw. To detect compressional forces for this press, semiconductor type strain gauges were attached directly to the lower end of a specially fabricated adjusting screw of the overload system. The gauges, which were attached on opposite sides of the screw, reflect the tablet compressional force as a function of the reduction of force on the screw. The plane passing through the strain gauges must be perpendicular to the axis of the roller on the overload system.

Modifications to the screw included a uniform "necked-down" section for application of the gauges and a hole running axially through the center of the screw to convey the lead wires from the machine. These alterations also increased the sensitivity of the strain gauged area of the screw to stress. The gauges were attached to the screw by the Kulite-Bytrex Corp., Newton, Mass., whose calibration of the screw indicated that an output of 7.5 μv. was generated per input volt per pound of applied force. The geometry of the release mechanism causes a ninefold reduction in detected stress, *i.e.*, 9 lb. of force on the punch reduces the force on the gauged screw by 1 lb. As indicated in the electrical schematic drawing (Fig. 1) for the compressional force instrumentation of the 540-35 press, the input voltage of the Wheatstone bridge circuit is 4.5 v. Thus, with this arrangement an absolute force of 270 lb. applied to the punches will generate a gauge output of 1.0 mv.

When the gauges are connected to the upper beam of the oscilloscope, the force of compression in pounds can be determined for each of the 35 stations as tablet formation occurs. The force of compression is an absolute force at the point of measurement. However, the indicated compressional force values include the friction in the upper punch guide and overload system. This frictional value could not be discerned when the signal on a strain gauged slug in the die cavity and the indicated force on the instrumented machine screw were compared. In this experiment the generation of a known load of 5000 lb. in the die cavity produced an equivalent reading on the instrumented screw.

The instrumentation of the ejection system for this press is shown in Fig. 2. A steel bracket was made to hold the two specially fabricated bolts to which semiconductor strain gauges were attached by the Kulite-Bytrex Corp. This bracket was mounted directly below the ejectional track or cam so that this track was supported .002 in. above the track bed by the strain gauged bolts. The track, although held in position by its original mounting bolts, was free to move vertically. When the track was struck by a lower punch in pushing a tablet from its die, the strain gauged bolts supporting the track detected this event.

Although the gauges were calibrated in terms of millivolts of output per volt of input per pound of applied force (1 mv./4.5 v./25 lb.), the ejectional force determined is a relative measurement of the actual force involved. Because a lever system is involved, an absolute equivalency would be possible only if the punches always struck the ejectional track at the exact same point and accomplished complete ejection when they did. Unfortunately, these conditions cannot be fulfilled because of the following reasons. (*a*) The contact point is changed

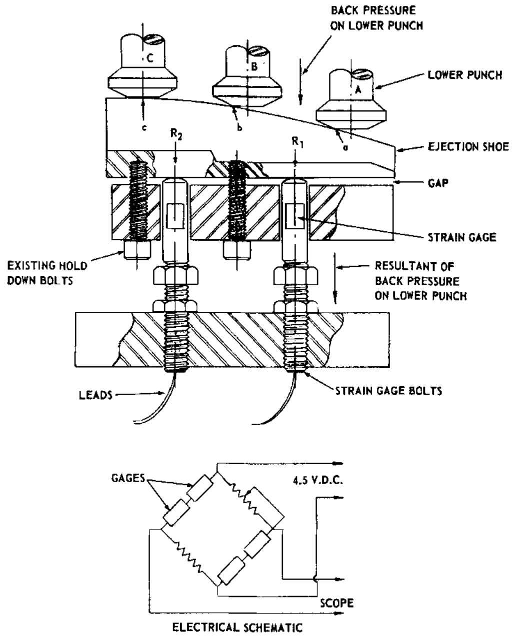

Fig. 2.—Instrumentation of 540-35 press. (Detection of ejectional force.)

when the machine settings, which vary with the formulation being compressed, are altered. (*b*) Random variations in the dimensions of the tools and press components also displace the contact point. (*c*) Complete ejection does not occur instantaneously at the initial point of contact.

When the gauges are connected by a Wheatstone bridge circuit to the lower beam of the oscilloscope (see Fig. 2), an ejectional force impulse will be detected as a single punch "A" strikes the track at point "a." This impulse represents the force of the contact which was applied to the entire track and created a reaction R_1 and R_2 in the two strain gauges. Disregarding the minimal horizontal shear force due to the angle of approach, the sum of R_1 and R_2 equals the applied force of ejection. Therefore, irrespective of the locus of this force on the track, the algebraic sum of the two reactions will always equal the force applied to the track by the punches.

Since two to three punch heads are in contact with the track at any time, the detected electrical impulse is a summation of the forces resulting at various points along the surface of the ejectional track. The literature pertaining to the instrumentation of single stroke presses (2, 4–7, 12, 13, 15) indicates that the force required to propel the tablet from its die is smaller than the force initially required to "break" the tablet loose from the die wall. If this is so, then the force applied by punch "A" as it first contacts the track will be much larger than the forces applied by punches "B" and "C" as they slide across the track. Our studies showed that this is the case. When ejection occurs, the oscilloscopic trace produced shows a sharp initial peak that slowly decreases until the next peak is generated (see Fig. 6).

Since the ejection event occurs somewhat later than the compression event for a given station, the peak ejectional force impulse is not displayed on the oscilloscope's screen directly below the compressional force impulse for that tablet. Rather, the ejectional impulse is displaced from its compressional impulse by five impulses for the 540-35 press.

One "side" of this 540-35 press was instrumented and thus only the compressional and ejectional forces occurring during this half of the revolution can be monitored. Obviously, the components of the opposite side of the press could be instrumented in a similar manner if desired.

Model BB2-27.—One of the major advantages of the 540 press—its high tablet production rate—unfortunately becomes a distinct drawback in research and development work. Although the press can be slowed to produce as few as 700 TPM, a great deal of tablet stock is still required for a satisfactory run. For this reason a tablet press with a lower tablet output was sought.

A Stokes model 538 press coating tablet machine was converted to a single stage rotary tablet press. The design of this press was originally based on the standard BB2-27 press. By changing the lower cam track design, the converted press performs like one-half of a standard BB2-27 machine. Thus, tablets are made on this press (termed $^1/_2$ BB2-27) in the conventional manner during one-half of the cycle. During the remainder of the cycle following ejection, the punches remain elevated with the lower punches level with the bed surface and the upper punches held in their uppermost position until the rear pull-down tracks are reached. The die filling, compressing, ejecting, and take-off sequence was not altered. Although this press has a capacity of only 375–750 TPM, the operation of this press and a standard Stokes BB2 press are identical. So that speed selections could be standardized, a tachometer was also attached to the press. This machine, then, is a very useful tool for tablet research and development studies and was instrumented in a similar manner to that used for the 540-35 press.[6]

A diagrammatic sketch showing the instrumentation and the electrical schematic outline for the compressional force detecting and monitoring system is shown in Fig. 3. Force applied to the lower punch during tablet formation is transmitted through the lower compression roll and the lever arm to produce a strain on the eyebolt of the pressure regulatory mechanism. The first step to instrument this press was to detach the entire lower, threaded portion of this cast iron eyebolt and to replace it with a specially fabricated steel section. This new part was threaded at the lower end as usual to accept the adjusting wheel and reduced in cross-sectional area at the upper end to increase its sensitivity to stress. Metal foil type strain gauges attached to this "necked-down" area measure the compressional force as tablet formation occurs. Our calibration of the gauges and our calculation of the mechanical advantage indicated that a force of 3,000 lb. on the lower punch produced a 1 mv. output by the gauges with 9 v. applied to the Wheatstone bridge circuit.

[6] Subsequent to our developments, the authors found that Brake (1) had briefly explored the partial instrumentation of a Stokes B2 rotary tablet press. Although Brake's instrumentation of the single stroke machine has been mentioned in the literature, to our knowledge no previous reference has been made to his work concerning the measurement of compressional forces on a rotary tablet press. Another investigator working with a B2 press (22) claimed that "during the tableting process the pressures exerted on the punches were measured and increased twice." Unfortunately, just how this was accomplished was not explained. The forces measured ranged from only about 1500 to 4000 lb.

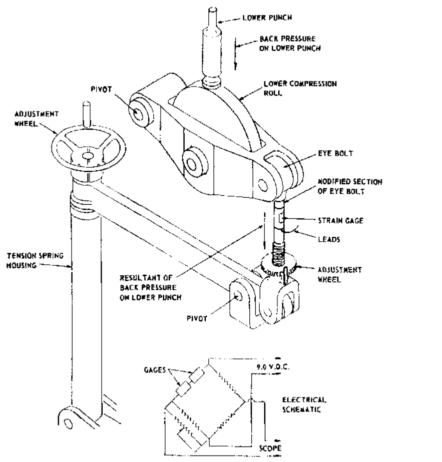

Fig. 3.—Instrumentation of BB2-27 press. (Detection of compressional force.)

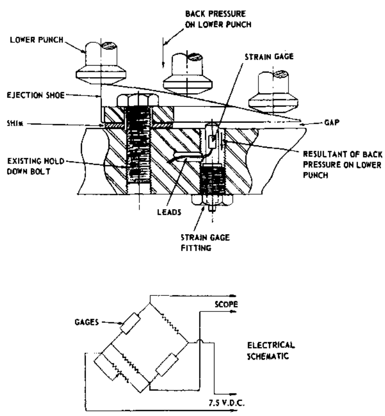

Fig. 4.—Instrumentation of BB2-27 press. (Detection of ejectional force.)

The installation of detectors to measure the ejectional force for the $^1/_2$ BB2-27 press was similar to that of the 540-35 press. Figure 4 shows this instrumentation and the electrical schematic diagrams for the monitoring system. The standard ejection track was shimmed to .002 in. above the track bed and the existing hold-down screw was used to secure it at the rear end. A bolt to which metal foil strain gauges were attached was positioned to support the front half of the ejectional track. Thus, the force generated when a punch hits the track while ejecting a tablet is transmitted to the bolt. Our calibrations indicated that, at a point directly above the gauged bolt, a force of 250 lb. was required to generate a gauge output of 1 mv. when 7.5 v. were applied to the Wheatstone bridge circuit. At a point near the leading edge of the track, the same force generates twice this electrical output, or 2 mv. However, because two to three punches are always in contact with the track at any given time, the electrical display is a composite of the forces being produced by these punches. Thus, as with the

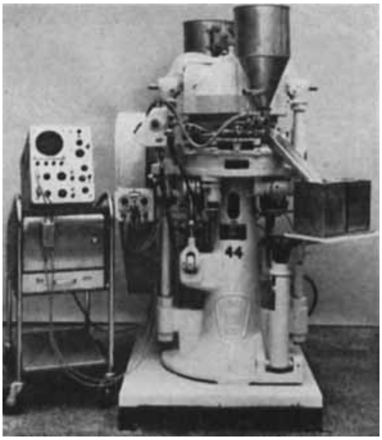

Fig. 5.—Instrumented production BB2-27 rotary tablet machine showing oscilloscope, control panel, and connections to strain gauges.

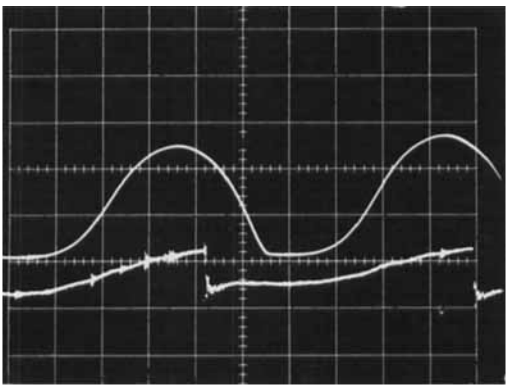

Fig. 6.—Photograph of oscilloscopic tracing for direct compaction mixture *A* compressed on 540-35 IRTM with Force-Flo-Feeder operating at 1000 TPM using 35-$^7/_{16}$ in. full oval punches. Calibration: upper trace (C.F.), one large division = 2700 lb.; lower trace (E.F.), one large division = 25 lb.; sweep, 20 msec./large division; left to right.

540-35 IRTM, only a relative measure of the ejectional force is obtained with this system.

Again, the dual-beam oscilloscope was used to amplify and display the generated impulses, and the camera was used to record the oscilloscopic displays for the studies. With this press the ejectional force impulse trailed the compressional force impulse by three impulses.

Both "sides" of two standard production BB2-27 presses have been instrumented in the described manner to measure compressional and ejectional forces. These IRTM's are in routine production use today (see Fig. 5). Furthermore, the eyebolts and ejectional tracks of a Manesty Bicota[7] have been instrumented in a manner similar to that shown in Figs. 3 and 4.

TYPE AND NATURE OF DATA OBTAINABLE

Figure 6 is a photograph of the compressional and ejectional force traces produced during tableting of a direct compaction mixture, *A*, containing three active ingredients with the 540-35 IRTM. The upper trace records the compressional force impulses and the lower trace records the ejectional force impulses. The latter is inverted, *i.e.*, its magnitude increases in a downward direction. For this photograph the horizontal sweep of the beams was increased so that only two consecutive compression and ejection events are shown. The compressional force for the first tablet (impulse to the left side of the photograph) is about 6480 lb. For the second tablet it is 7020 lb. For the first ejectional event displayed, the initial peak height represents a force of about 27 lb., while a force of about 32 lb. is registered for the ejection of the second tablet. As explained, the ejection events shown do not correspond to the compressional curves depicted.

By decreasing the horizontal sweep and making a time exposure, the photograph shown in Fig. 7 was obtained. In this run, however, the upper punches were removed from stations 31 and 33, accounting for the "blanks" in both tracings. It can be observed that an ejectional force impulse is displaced to the right by five impulses from its compressional force counterpart. The usual variation in both the compressional and ejectional force impulse heights was accentuated because the experimental direct compaction mixture *A* being compressed did not flow well. The uniform compressional pulse heights at the right side of the picture occurred because the press "unloaded" as the tablets were compressed, *i.e.*, the development of excessive pressures was automatically prevented by the hydraulic-mechanical overload system of the press. When this occurs, there is a plateau in the individual compressional force curve since additional force cannot be applied to the tablet or punches.

The oscilloscopic displays obtained from the $^1/_2$ BB2-27 IRTM are similar to those shown for the 540-35 IRTM. An example is shown in Fig. 8 where the horizontal sweep has been increased on the left half to show the characteristics of individual impulses and then decreased on the right half to

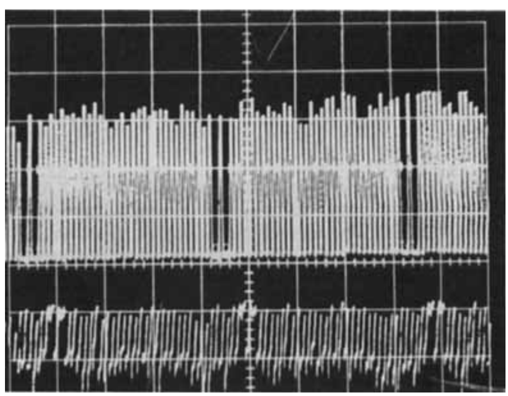

Fig. 7.—Photograph of oscilloscopic tracing for direct compaction mixture *A* compressed on 540-35 IRTM with Force-Flo-Feeder operating at about 1000 TPM using 35-$^7/_{16}$ in. full oval punches (upper punches removed from stations 31 and 33). Calibration: upper trace (C.F.), one large division = 2700 lb.; lower trace (E.F.), one large division = 25 lb.; sweep, 1 sec./large division; left to right.

[7] Manesty Machines Ltd., Liverpool, England.

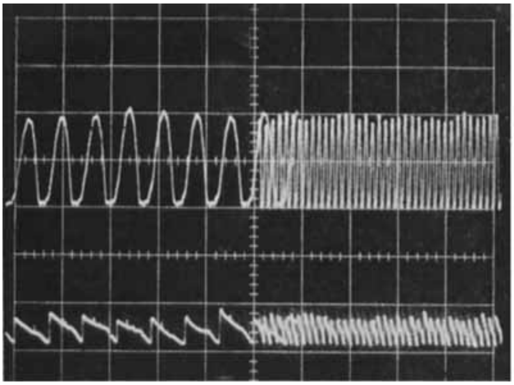

Fig. 8.—Photograph of oscilloscopic tracing for direct compaction mixture *B* compressed on BB2-27 IRTM with Force-Flo-Feeder operating at a speed of about 430 TPM using 27-$^{7}/_{16}$ in. full oval punches. Calibration: upper trace (C.F.), one large division = 3080 lb.; lower trace (E.F.), one large division = 125 lb.; left sweep, 0.2 sec./large division; right sweep, 1 sec./large division; left to right.

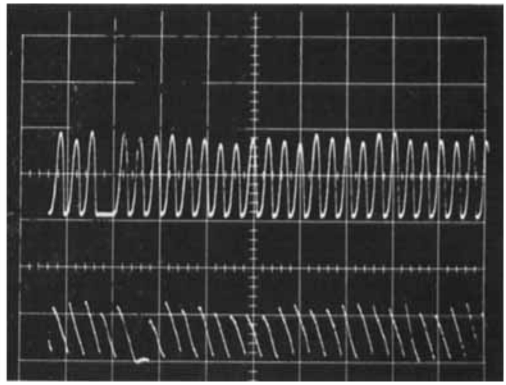

Fig. 10.—Photograph of oscilloscopic tracing of conventional granulation D compressed on BB2-27 IRTM operating at about 400 TPM using 26-$^{7}/_{16}$ in. full oval punches (upper punch removed from station 1). Calibration[8]: upper trace (C.F.), one large division = 2360 lb.; lower trace (E.F.), one large division = 83 lb.; sweep, 0.5 sec./large division; left to right.

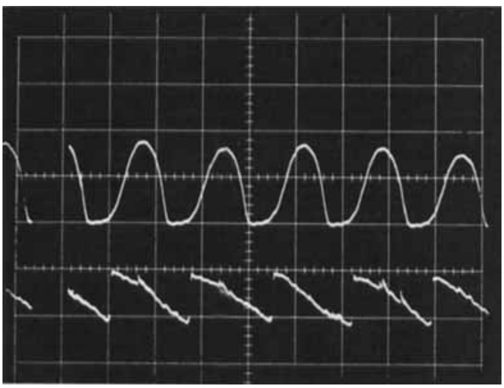

Fig. 9.—Photograph of oscilloscopic tracing for conventional granulation D compressed on a BB2-27 IRTM operating at about 400 TPM using 27-$^{7}/_{16}$ in. full oval punches. Calibration[8]: upper trace (C.F.), one large division = 2360 lb.; lower trace (E.F.), one large division = 83 lb.; sweep, 0.1 sec./large division; left to right.

"squeeze" the series of impulses together. These compressional force impulses are quite uniform. One explanation is that this particular direct compaction mixture *B*, containing the same three active ingredients as *A*, flowed extremely well. The ejectional force tracings are not inverted in Figs. 8, 9, and 10; hence, the magnitude of the force increases in an upward direction.

Figures 9 and 10 are photographs obtained while a conventional granulation D containing the same three active ingredients was being compressed on the $^{1}/_{2}$ BB2-27 IRTM.[8] Figure 9 shows the individual impulses, while Fig. 10, obtained by decreasing the sweep and removing the upper punch from one station, shows the displacement of the ejectional force impulse to the right of the corresponding compressional force impulse by three impulses. There was more compressional force uniformity for this granulation than there was for the poorly flowing direct compaction mixture *A* shown in Fig. 7. However, the good flowing direct compaction mixture *B* pictured in Fig. 8 showed the most nearly uniform compressional force impulse heights of the three.

Various methods can be used to measure the individual heights for a series of impulses. Photographic prints or transparencies can be projected onto a calibrated grid or measured directly by a specially scaled transparent ruler. The mean of a series of impulse heights can be determined and used to calculate the force involved in the preparation of that sample of tablets. For example, in Fig. 8 the mean pulse height for the left side of the picture was found to be 1.71 cm. Since 0.9 cm. is equivalent to 3080 lb., the average compressional force generated during the compression of these tablets is $1.71 \times 3080 \div 0.9$ or about 5850 lb. The average ejectional force calculated in a similar manner is $0.52 \times 125 \div 0.9$ or about 72 lb. Compressional and ejectional force data can be obtained in this manner to define or describe an individual tableting run. All force measurements can be converted into pressure values by simple calculation involving the area of the punch faces. It is important to remember that the compressional force measurements are in terms of absolute force at the point of measurements and include any slight friction components of the upper punch guide and overload systems. The ejectional force measurements are relative values with respect to the machine, the machine settings, and the tools. The ejectional force is related to the stock, the size and shape of the punches, the depth of compression, and the size or weight of the tablets being produced.

The material presented describes the type and nature of data that can be obtained with instrumented rotary tablet machines. Some of the ways that

[8] The calibrations differ between Figs. 9 and 10 and Fig. 8 because deliberate alterations to the circuitry and cross-sectional area were made to increase the sensitivity of the system. Presently, by adjusting the circuitry, the sensitivity has been further increased for the BB2-27 IRTM.

such data have been used to study a variety of tableting problems will be presented in part II of this series (26).

SUMMARY

The proposed design requirements to measure and monitor compressional and ejectional forces developed on rotary tablet machines have been fulfilled by the two instrumented presses described here. The forces are detected by strain gauges attached to strategic components of the press remotely located from the sites of action. The detected forces are monitored on a dual-beam oscilloscope connected through Wheatstone bridge circuits to the individual compressional and ejectional force sensing strain gauges. Diagrams are included to show the strain gauging and electrical circuits. Permanent records are obtained by taking pictures of the transmitted displays with a Polaroid-backed oscilloscope camera. Photographs are used to illustrate the type and nature of compressional and ejectional force data obtainable from the instrumented presses.

Thus, two instrumented rotary tablet machines, the Stokes models 540-35 and $^1/_2$ BB2-27, are now available for research and development projects. Other tablet machines, similarly equipped, have been used to monitor routine tablet production runs.

ADDENDUM

Since the time this paper was prepared and presented at the annual meeting of the AMERICAN PHARMACEUTICAL ASSOCIATION in May 1963, additional studies on the instrumentation of rotary tablet machines have been reported.

Shotton and co-workers (23) bonded strain gauges to the shanks of one upper and one lower tablet punch and used radio telemetry to transmit the compressional force to the recorder. The press was a Manesty D-3, 16 punch, rotary tablet machine in which all of the tablet punches had been removed except for a single punch and die set. The machine had to be hand turned.

Fuhrer (24) discussed the pressure distribution in tableting with a study on compression curves in rotary tableting presses.

Recently, Wray *et al.* (25) reported on an instrumented Stokes BB2 rotary tablet machine similar to that described in this paper. These workers were able to monitor simultaneously the upper and lower compressional forces from both a set of instrumented punches and instrumented upper and lower compression rolls and ejection forces from an instrumented lower punch and a redesigned ejection cam.

The rotary tablet machine instrumented by Shotton is a research tool incapable of operating at high speeds. The instrumented rotary tablet machines described in this paper and the one subsequently modified by Wray may be utilized to study typical tablet development and production problems under dynamic conditions.

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