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Short Communications

Simultaneous measurement of force and displacement in an automatic capsule filling machine

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Instrumentation of tablet presses has enabled scientists to study compaction profiles as a part of formulation development and as a means to monitor and control production. Various instrumentation systems have used resistance strain gauges, displacement transducers, and piezoelectric transducers. Recently, modern, fully automatic, capsule-filling equipment employing filling principles similar to tablet compression has been instrumented (Cole and May, 1975; Small and Augsburger, 1977) to measure the compression and ejection forces.

The mounting of displacement transducers has enabled scientists to determine the work involved in compaction processes. Although the importance of such measurements seems indisputable, only few such studies have been reported in the literature relating to tableting and no such attempt has been made in encapsulation. Studies involving compaction profiles and force–displacement curves (F–D curves) have been shown, notably by de Blaey and coworkers (1970, 1971, 1972), to offer a very powerful means of evaluating formulations for certain inherent compaction properties and have facilitated lubricant evaluation. In this communication, an instrumentation technique to generate force–displacement curves in a fully automatic capsule filling [1] operation is described.

An AC–AC linear voltage displacement transducer [2] (LVDT) was used to measure the displacement of the previously instrumented dosator piston (Small and Augsburger, 1977). This piston is responsible for both the compression of the powder slug and the ejection of the slug from the filling head. A major problem that had to be overcome in making an effective linkage between the piston and the LVDT is the rotation of the piston during displacement. This rotation occurs because a cross-bar through the piston collar rides in a quarter-turn slot in the dosator housing. This problem was resolved by mounting a brass platform (Fig. 1A) on the cross-bar. Resting on the platform is a spring loaded rod (Fig. 1B) which, in turn, is threaded onto the core of the LVDT. The LVDT (Fig. 1C) is supported over the platform in inverted position by means of a specially designed bracket (Fig. 1D) which is clamped to the dosator housing. Thus,

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[1] Zanasi LZ-64 Automatic Capsule Filling Machine, Z-Packaging, Nanuet, N.Y., U.S.A.

[2] AC-AC LVDT, Series 293-000, Trans-Tek Inc., Ellington, Conn. 06029, U.S.A.

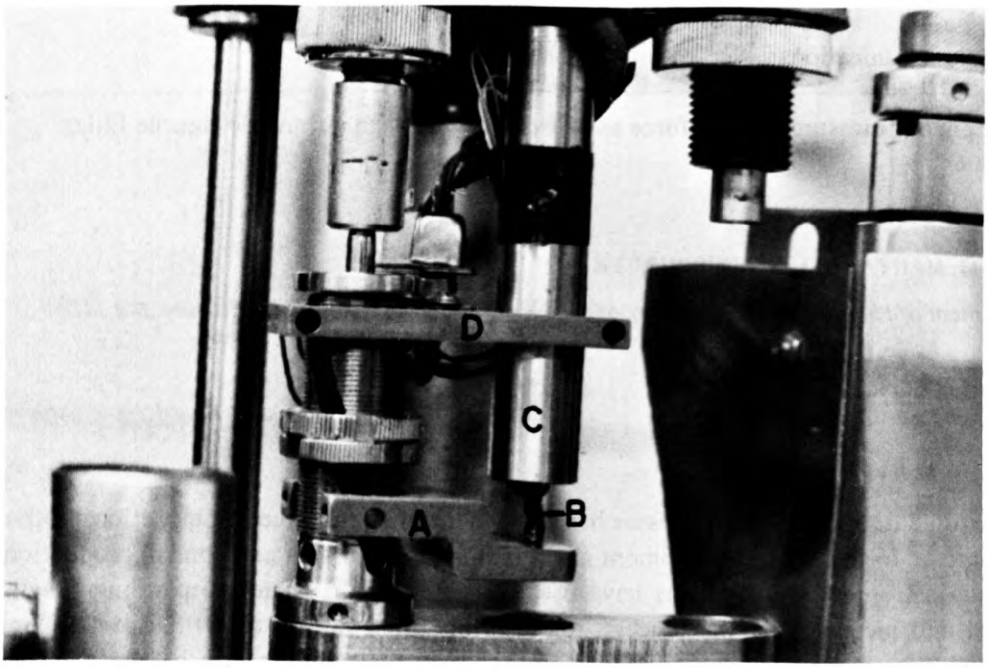

Fig. 1. View showing mounting of LVDT on instrumented dosator. Key: A, brass platform; B, spring loaded rod; C, LVDT; D, support bracket.

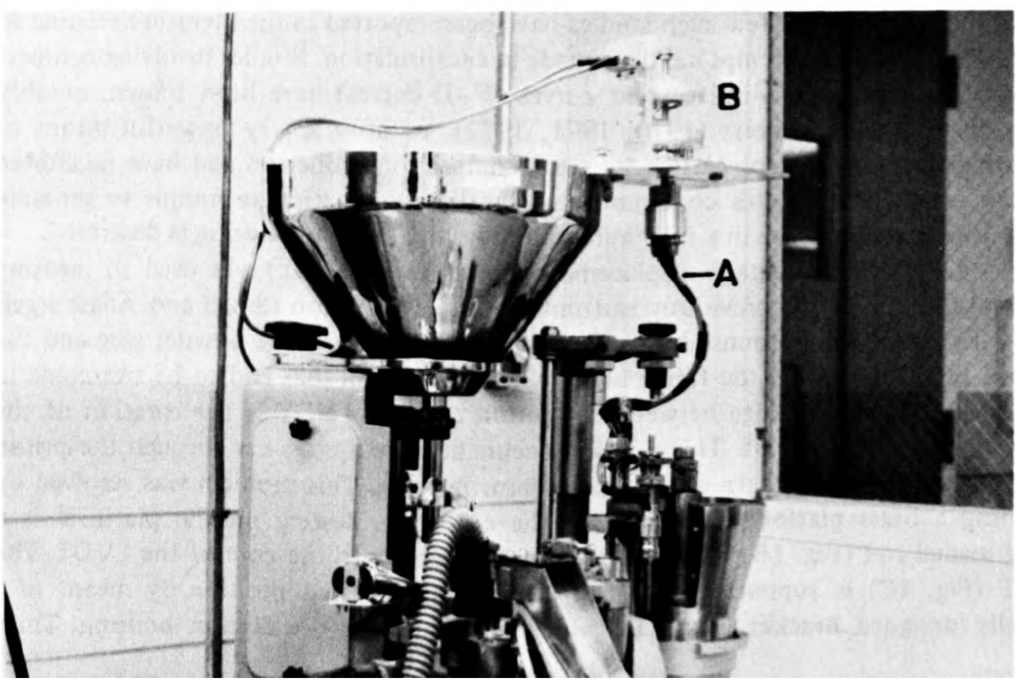

Fig. 2. Overall view of dosing assembly showing cables (A) connecting the dosator with the mercury swivel (B).

during the rotational displacement of the piston, the platform maintains continuous contact with the spring loaded rod.

Two sets of cables (Fig. 2A), one for the LVDT and the other for the piston are connected to a mercury swivel [3] (Fig. 2B) via 10-conductor connectors. The mercury swivel prevents the twisting of the connecting cables during the 360° continuous rotation of the dosator arm carrying the instrumented dosator and LVDT. The mercury swivel is a noise-free commutator-slip ring assembly which utilizes platinum electrodes in a mercury pool. This design eliminates the noise which the conventional brush and slip ring devices create. The swivel is, in turn, connected to the monitoring equipment. The bridge unbalance voltage of the strain gauged dosator piston and voltage output of the LVDT were monitored by means of separate carrier preamplifiers [4], the outputs of which provided a continuous trace of the compression and ejection events on a dual channel oscillographic recorder [5] or oscilloscope [6].

Mechanical operation of the LVDT linkage

As the piston moves, the cross bar along with the platform displaces to the same extent. As the platform displaces, the spring loaded rod attached to the core also moves. The movement of the core inside the LVDT coil causes a voltage change proportional to the displacement which is measured by the monitoring device.

The piston displacement was calibrated directly by applying known displacement while simultaneously recording the corresponding deflection of the galvanometer pen of the recording system. Each mm displacement of the piston corresponded to 4 mm deflection of the galvanometer pen.

Force–displacement–time traces

To generate force and displacement traces, No. 1 capsules were filled with microcrystalline cellulose [7] which was lubricated with 0.01% magnesium stearate [8]. A twin-shell blender [9] was used. Blending was carried out for 15 min with the intensifier bar running for the last 2 min. The capsule filling machine was set to run at its maximum powder bed height of 49.4 mm. The instrumented piston was set to a height of 12 mm. The length of the compression knob was set to give a theoretical piston displacement of 5 mm.

Typical force and displacement traces observed with microcrystalline cellulose are shown in Fig. 3. When the dosator enters the powder bed, no force develops until the dosator reaches a depth corresponding to the piston height. With the continued penetration of the dosator, this force rises to a maximum at the maximum penetration of the dosator, but there is no piston displacement. This is the precompression force (Fig. 3A) which develops as the powder sectioned by the dosator is compressed against the sta-

[3] Technical Concepts, Bronx, N.Y. 14063, U.S.A.
[4] Model 8805A, Hewlett-Packard, Palo Alto, Calif. 94306, U.S.A.
[5] Model 7702B, Hewlett-Packard, Palo Alto, Calif. 94306, U.S.A.
[6] Oscilloscope System 5103N, Tektronix, Beaverton, Oreg. 97005, U.S.A.
[7] Avicel pH 102, FMC Corp., Newark, Dela 19711, U.S.A.
[8] Amend Chemicals, Irvington, N.J. 07111, U.S.A.
[9] Model LB-3794, The Patterson-Kelly Company, Inc. Stroudsburg, PA., U.S.A.

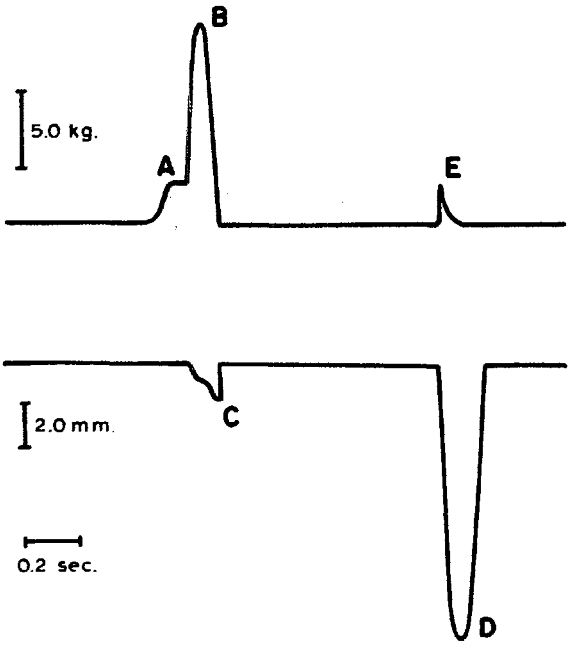

Fig. 3. Typical force and displacement traces for microcrystalline cellulose (0.01% magnesium stearate). Key: A, precompression force; B, compression force; C, compression displacement; D, ejection displacement; E, ejection force.

tionary piston during the downward stroke of the dosing unit (Small and Augsburger, 1977).

After the dosing unit completes its downward stroke, the force trace rises again (Fig. 3B). This rise in compression force reflects the compression of the powder in the dosator by means of the downward displacement of the piston to a maximum, in this instance, of 14.0 kg force. Although the compression knob was set for a theoretical piston travel of 5 mm, actual maximum displacement was only 1.75 mm (Fig. 3C). This difference is attributable to the fact that the compression knob is spring loaded by means of an overload relief spring mounted in the compression knob holder. Thus, the difference of 3.25 mm is taken up in the deformation of that spring.

It is also interesting to note that the development of the maximum compressive force preceded the point of maximum piston displacement by about 0.04 sec. This appears attributable to the action of the overload relief spring and the movement designed into this machine. After the point of maximum compression, the compression force begins to decline as the compression arm rises. However, for a finite period of time, the compression knob remains in contact with the piston as the spring recovers. Thus, even though the compression force is declining, the piston continues to be loaded for a short interval until the compression arm lifts the compression knob completely away from the piston. The small additional displacement observed beyond the point of maximum compression force may be due in part to additional consolidation of the powder; however, there also is opportunity for a slight downward displacement of the slug to occur during this brief interval. This opportunity occurs because after the point of maximum compression force, both the dosator support arm and the compression arm lift together, the compression arm rising more rapidly and to a greater height. This action thus serves to provide a small clearance at the bottom of the dosator during the interval that the relaxation of the spring maintains contact between the compression knob and the piston.

An examination of the force–displacement traces for ejection shows that the force trace (Fig. 3E) rises to a maximum at the onset of displacement (Fig. 3D). This is to be expected since sufficient force must be developed by the piston before it can displace the slug.

Studies are underway aimed at further clarifying the relationship between these traces and slug formation and ejection. In addition, these force–displacement traces can be recorded as an X–Y plot which may be integrated to obtain the work of compression or work of ejection. It is hoped that such information will prove useful in the study of capsule formulations.

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