Pharmaceutical Research, Vol. 12, No. 2, 1995

Report

Construction of an Intermittent-Motion Capsule Filling Machine Simulator

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Received May 20, 1994; accepted September 7, 1994

A pneumatically operated apparatus is described which simulates the forces generated by and the component movements encountered in a Macofar 13/2 dosator type capsule filling machine. Force transducers are fitted to the dosing piston and dosator tip, and the movement of the dosator piston and the powder bed followed by displacement transducers. Calibration of the transducers is described. The output from the transducers is collated, stored and manipulated by microcomputer. The manufacturing parameters which can be studied using this apparatus are discussed.

KEY WORDS: capsule; capsule filling; simulator.

INTRODUCTION

The concept of fitting force and distance transducers to tablet presses was developed principally by Higuchi *et al.* (1), who introduced the term 'instrumented tablet machine'. Since that time, instrumentation of tablet presses has become common, and many presses are routinely fitted with transducers during manufacture. Information obtained from instrumented tablet presses has contributed greatly to the understanding of the tabletting process (2).

In contrast, the instrumentation of capsule filing machinery has received comparatively little attention. The forces to be measured are low (a few hundred newtons) compared to the kilonewtons encountered in tablet manufacture, and hence a sensitive force measuring system is needed. Furthermore the fitting of transducers, particularly displacement transducers, demands that they be secured to a massive fixing point, otherwise reliable results cannot be obtained. Though such a mass is present in a tablet press, it is not so readily available in most capsule filling machines.

Automatic capsule filling equipment can conveniently be divided into two types, the dosating nozzle type, as typified by Zanasi, Macofar and mG2 models, and tamping devices such as the GKF machines made by Hofliger and Karg. Force and displacement transducers have been fitted to Zanasi machines by, among others, Cole and May (3), Small and Augsburger (4) and Mehta and Augsburger (5).

The use of simulators has received considerable attention in tablet compression, some advantages of simulators being that small amounts of powdered material may be used, and a range of different operating conditions can be imitated (6). The use of simulated capsule filling equipment has also been reported. Jolliffe *et al.* (7) reported the use of a simulated mG2 capsule filling machine, and this has been used extensively by Tan and Newton (8). A filling rig designed to simulate a Zanasi type machine was described by Woodhead (9).

The capsule filling machine which is the subject of this study is the Macofar MT13-2 (Macofar SRL, Bologna, Italy). This has a dosating mechanism similar to that of the Zanasi, but it is simpler in that there is no twisting of the dosator piston relative to the dosator body during compression and ejection strokes. However due to the similarity between this machine and the Zanasi AZ20 model, it was considered desirable that the speed range of both machines should be imitated by the simulator if possible.

CONSTRUCTION OF THE STIMULATOR

The aim of any simulator must be to imitate the motion of the components of an actual machine, and the forces generated therein. Subsidiary aims are that the apparatus is inexpensive, and that relatively small amounts of powdered material are required for its operation.

DETERMINATION OF DOSATOR VELOCITIES

No information on the actual velocities of the dosating tube and piston of the Zanasi AZ20 and Macofar MT13/2 machines was available in the literature, 'speed' being quoted as machine output ie the number of capsules filled in unit time. By fitting displacement transducers to both these machines, it was possible to monitor the actual dosator movement. Displacement time curves were obtained and velocities calculated from them. The velocity results are shown in Table I using two different output settings.

Thus the aim was to design a simulator with a maximum dosator tube speed of 0.6 ms^{-1} and a maximum piston speed of 0.8 ms^{-1}, thereby encompassing the speed ranges expected to be encountered in both the Macofar 13/2 and the

Table I. Dosator and Piston Velocities on Macofar MT13/2 and Zanasi AZ20 Capsule Filling Machines.

	Machine	Output (Capsules hr^{-1})	Velocity (ms^{-1})
Dosator velocities during precompression stage	Macofar MT13/2	6600	0.301
	Macofar MT13/2	12600	0.600
	Zanasi AZ20	15000	0.242
	Zanasi AZ20	21000	0.350
Piston velocity during compression	Macofar MT13/2	6600	0.220
	Macofar MT13/2	12600	0.505
	Zanasi AZ20	15000	0.120
	Zanasi AZ20	21000	0.160
Piston velocity during ejection	Macofar MT13/2	6600	0.272
	Macofar MT13/2	12600	0.834
	Zanasi AZ20	15000	0.453
	Zanasi AZ20	21000	0.653

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Zanasi AZ20 machines. This proved an impractical target, but maximum dosator and piston speeds of about 0.5 ms^{-1} and 0.6 ms^{-1} respectively were achieved, covering about 75% of the range of the Macofar and virtually the whole range of the Zanasi machine.

Two decisions were taken at the outset of the work. The first was that the simulator should be driven pneumatically. Tablet press simulators are driven hydraulically, a factor which contributes significantly to their cost and complexity, but which is necessary because of the combination of high speeds and forces involved. Though the dosator and piston speeds in capsule filling machinery are similar to those of the punches in a tablet press, the forces are low enough to permit pneumatic operation.

In a conventional Macofar machine, the dosator tubes are plunged into the powder bed, a plug of powder is withdrawn and is then ejected. To follow this sequence of operations would significantly add to the complexity of the apparatus, and so it was decided that the dosator mechanism should remain stationary and the powder brought to it by means of a moving powder bowl. Thus references to 'dosator speed' are in fact the speed at which the powder bowl moves towards the dosator.

The simulator was constructed from a 2.54 cm square steel box section framework bolted to a small rigid bench (Truline Engineering Ltd, Newport, Gwent, UK). The sequence of operations is summarized in Figure 1.

The bowl containing suitably consolidated powdered material is raised by pneumatic cylinder A and the dosator tube enters the powder bed. Thus the dosator tube becomes filled with powder. This is termed 'precompression' (Figure 1.ii). By means of pneumatic cylinder B, a tamping force may be exerted to the piston which in turn compresses the powder in the dosator chamber to form a plug (Figure 1.iii). Cylinder A now retracts, and the powder bowl descends. By means of a horizontal shuttle movement of cylinder D, cylinder C replaces cylinder B directly over the dosator piston. Cylinder C then extends, ejecting the powder plug (Figure 1.iv). All components now return to their starting positions. Speeds of cylinders A, B and C can be altered by flow control valves so that a range of dosator and piston speeds can be obtained. There is no need for variable speed on cylinder D.

THE PNEUMATIC SYSTEM

The pneumatic circuit diagram is shown in Figure 2. The system works on the cascade principle. Engaging the start button produces an automatic chain of events, the movement of a particular cylinder or valve triggering the movement of the next component.

Air is supplied from a cylinder at 20 MPa, reduced to 0.7 MPa at the cylinder outlet and to 0.6 MPa (the operating pressure) at a second regulator mounted on the simulator frame. The air supply is divided into two 'groups' GI and GII, depending on the switching condition of valve DCV5.

Immediately before the start button is pressed, cylinder D is in the retracted position because it is being supplied by GI air from DCV4. Pressing the start button sends a GI signal to valve DCV1. This in turn sends a GI signal on to cylinder A via a flow control valve, causing A to extend. It should be noted that each of the 4 cylinders A to D has a flow control valve on the extend and retract ports. Each valve acts as a speed controller by restricting the flow of air into the cylinder. The amount of restriction and hence the speed of extension/retraction is adjusted by means of a slot headed screw in the valve.

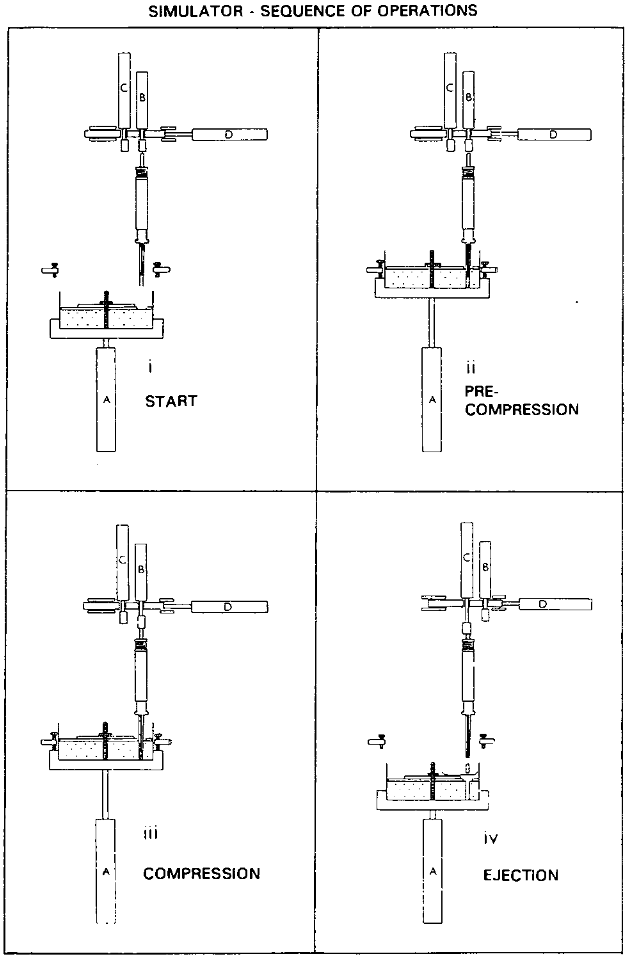


Fig. 1. Sequence of operations of the capsule filling machine simulator.

Cylinder A supports the powder bowl. As A extends, it strikes the limit switch A+ which sends a signal to timer T_1. T_1 is set to give a predetermined time delay. At the end of the delay, a signal is sent from T_1 to DCV3, which in turn sends GI air via a pressure regulator to cylinder B causing it to extend. (B applies a tamp to the dosator piston). As B reaches the end of its extension stroke, the fall in pressure ahead of the piston causes NOT gate B+ to send a signal to timer T_2. T_2 is set to give a predetermined time delay. At the end of the delay, a signal is sent to DCV5 which switches air from GI to GII.

GII air actuates DCV2 which sends GII air to cylinder B causing it to retract. NOT gate B− detects the decay in pressure as cylinder B completes its retract stroke and this sends a signal to DCV1 which causes cylinder A to retract, thereby lowering the powder bowl. As A retracts it triggers limit switch A− which in turn sends a signal to DCV4 which switches over and sends GII air to cylinder D which extends. This causes the shuttle mechanism carrying cylinders B and

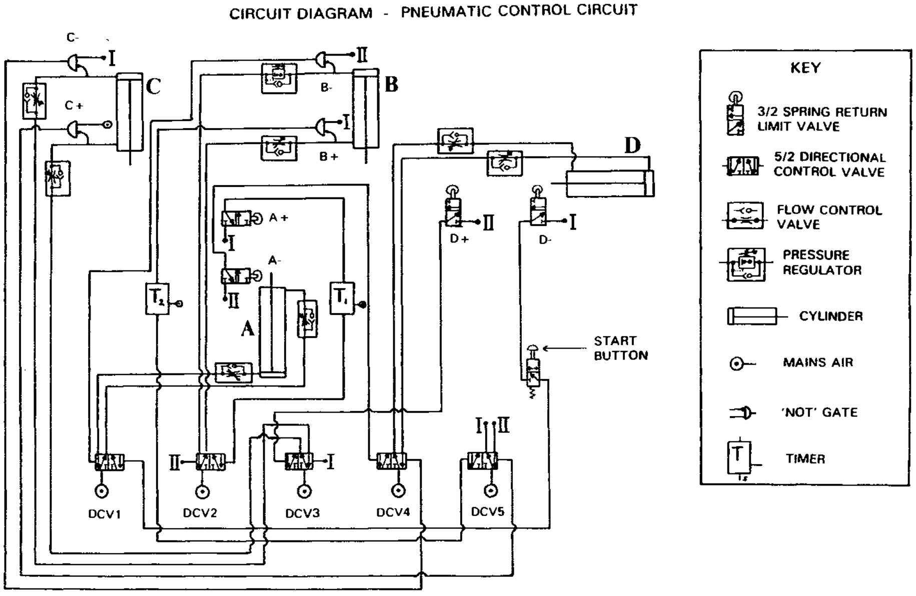


Fig. 2. Pneumatic circuit diagram of the capsule filling machine simulator.

C to move to the left, aligning cylinder C directly over the dosator.

Limit switch D+ is triggered, sending a signal to DCV3, which switches it over, sending GII air to cylinder C. Cylinder C extends, ejecting the plug of compressed powder from the dosator funnel and the corresponding NOT gate C+ sends a signal to DCV5. DCV5 switches over, putting GI air back into the system. This causes DCV3 to switch over, sending GI air out to cylinder C and retracting it. NOT gate C− is activated, sending a signal to DCV4. DCV4 switches over sending GI air to cylinder D causing it to retract. This returns the shuttle to its resting position and ends the cycle. Finally as D retracts it triggers limit switch D− sending GI air onto the start button in readiness to start the next cycle.

TRANSDUCERS

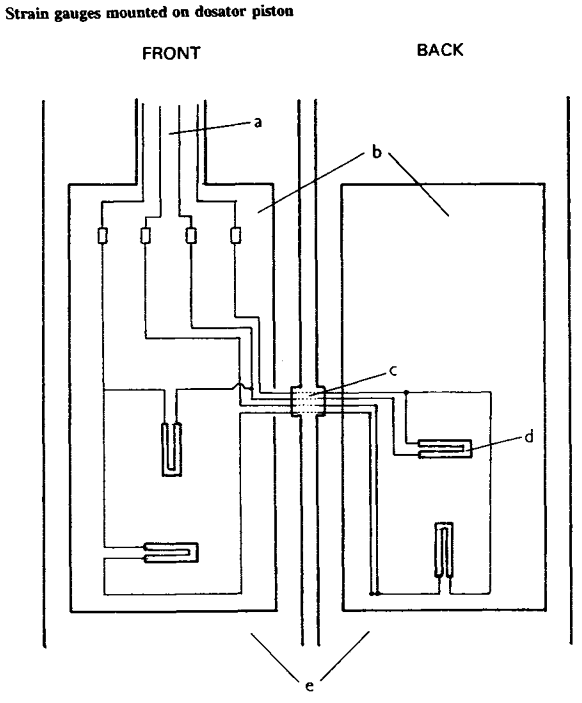
Displacement Transducers

Two displacement transducers are fitted to the simulator. A long stroke transducer (Model DCT3000A, RDP Electronics Ltd, Wolverhampton, UK) was used to monitor movement of the powder bowl, the tip of the actuator rod pressing against the edge of the powder bowl platen. A smaller transducer (Model DCT1000A) was used to follow movement of the dosator piston. The transducer was operated by a small actuating arm, since direct contact between the piston and the actuator was not possible.

Force Transducers

Force transducers are fitted to the dosator piston and to the dosator funnel. Because of the anticipated magnitude of the forces generated in the simulator, semiconductor strain gauges were used (Model UEP 350-060, Kulite Sensors, Basingstoke, UK). These have relatively high outputs at modest strain, whereas foil gauges would require high amplification with attendant electrical noise problems (10).

The transducers fitted to the dosator piston from the four arms of a full Wheatstone bridge circuit. Two gauges are mounted on each side of the piston, and a small groove was machined across the circumference of the piston so that the wires could conveniently be routed to the opposite side. (Figure 3). A wider groove was also machined up the length of the piston to contain the cable leading to the strain gauges.



a - Groove for cable

b - Flattened area for strain gauges

c - Groove for interconnecting wires

d - Strain gauge

Fig. 3. The mounting of strain gauges on the dosator piston.

About 10 mm was removed from the flared tip of the piston and a threaded tip inserted in its place so that alternative tips could be fitted if required.

The relationship between the axially applied force and the force transmitted radially to the die wall in a tablet press has been found to be useful in the study of tablet compression (11). Since the possibility may exist of similar relationships in the present work, force transducers were fitted on the outer surface of the dosator funnel 6 mm from its tip, this being midway between the tip and the anticipated plug length of 12 mm. Wires from the strain gauges were terminated at a piece of Veroboard. The cables were then attached by means of small crocodile clips to facilitate removal of the funnel for cleaning.

POWER SUPPLY

The power supply to all transducers was by two bench power supply units, Radiospares Type 611-420 giving 5v DC for the strain gauges and Type 610-461 giving 20v DC for the displacement transducers (Radiospares, Corby, UK).

DATA ACQUISITION AND MANIPULATION

Signals from the transducers were fed into Microlink data acquisition hardware (Biodata Ltd, Manchester, UK). Analogue signals were digitalised, the rate of sampling being governed by a high speed clock working either sequentially or in a burst mode when samples are collected from all channels in rapid succession, followed by a pause. The acquisition software was HSDC (High Speed Data Collection) supplied by Biodata Ltd. This was run on an Amstrad PC 1640 microcomputer fitted with an IEEE488 interface card (Biodata Ltd). After collection, the raw data was converted to ASCII format and transferred to a Compuadd 320SC computer containing a Quattro-Pro spreadsheet program (Borland, Twyford, UK) for further manipulation.

CALIBRATION

The LVDT's were calibrated by clamping them securely above a solid steel block. Flat pieces of steel of known dimensions were inserted between the tip of the armature of the LVDT and this block. Linearity ($r > 0.999$) was obtained after about 20% of the armature displacement, and during experimental use, it was ensured that the LVDT's were only used at or near their midpoint position.

The dosator piston strain gauges were calibrated by a static loading method, the complete dosator being removed from the simulator and placed in a specially made jig. A 'top hat' spacer ensured intimate contact between the piston and the pan of an electronic balance. Force was applied to the top of the dosator piston by admitting compressed air into the cylinder and the value of the force read from the balance, the output of the strain gauges being recorded simultaneously. Excellent linearity between load and transducer output was obtained ($r > 0.999$).

The funnel gauges were calibrated by the method which has been successfully used in the calibration of strain gauges fitted to the die walls of tablet presses (11). Cylindrical plugs composed of a nitrile rubber cylindrical extrusion lubricated with light liquid paraffin were inserted in the open end of the funnel. The simulator was operated normally and radial and axial signals collected from various plug lengths. Data for plug lengths between 5 and 8 mm was subjected to regression analysis, all slopes having a correlation coefficient of > 0.996.

The simulator can be set to operate in a variety of modes, all at a range of dosator and piston speeds.

(a). Precompression simulation, when the powder plug is formed solely by the dosator as it descends into the powder bed. No additional compression i.e., tamping is applied.

(b). Constant displacement simulation, when the powder has already been partially precompressed as described above but where an additional tamp is applied by the dosator piston. The displacement of the piston is accurately controlled so as to be constant stroke after stroke. The displacement must be less than that which would cause the overload spring to operate on a capsule filling machine.

(c). Constant pressure simulation, when powder has been precompressed as above and then the piston is allowed to travel as far as possible until the resistance of the powder to undergo further consolidation equals the applied compression pressure.

The following information can be collected for every plug. Compression pressure–the pressure acting on the dosator piston as the powder consolidates inside the funnel during precompression or compression. Radial pressure–the pressure transmitted radially to the funnel wall as powder consolidates during precompression or compression.

Residual axial pressure–the pressure transmitted to the piston after the plug has had time to undergo particle rearrangement or elastic recovery prior to ejection. Residual radial pressure–the pressure transmitted radially after the plug has had time to undergo particle rearrangement or elastic recovery prior to ejection. Axial ejection pressure–the pressure exerted by the piston during the ejection of the plug from the dosator funnel. Radial ejection pressure–the pressure transmitted radially as the piston ejects the powder plug.

In addition the following data can be collected by a combination of physical and electronic measurements: plug weight, plug density (before ejection), plug length (before and after ejection) and powder bed density. These can then be related to the pressure and displacement data.

ACKNOWLEDGMENTS

The support of Parke-Davis Warner-Lambert and in particular that of Dr. John Garner, former R & D director of Parke-Davis, Pontypool, is gratefully acknowledged.

REFERENCES

1. T. Higuchi, E. Nelson, and L. W. Busse. The physics of tablet compression, 3: design and construction of an instrumented tablet machine. *J. Amer. Pharm. Assoc. Sci. Ed.* 43:344–348 (1954).
2. P. Ridgway-Watt. *Tablet machine instrumentation in pharmaceutics*, Ellis Horwood, Chichester, 1988.
3. G. C. Cole and G. May. The instrumentation of a Zanasi LZ/64 capsule filling machine. *J. Pharm. Pharmacol.* 27:353–358 (1975).
4. L. E. Small and L. L. Augsburger. Instrumentation of an automatic capsule filling machine. *J. Pharm. Sci.* 66:504–509 (1977).
5. A. M. Mehta and L. L. Augsburger. Simultaneous measure-

ment of force and displacement in an automatic capsule filling machine. *Int. J. Pharm.* 4:347–351 (1980).

6. S. Bateman. High speed compaction simulators in tabletting research. *Pharm. J.* 240:632–633 (1988).
7. I. G. Jolliffe, J. M. Newton, and D. Cooper. The design and use of an instrumented mG2 capsule filling machine simulator. *J. Pharm. Pharmacol.* 34:230–235 (1982).
8. S. B. Tan and J. M. Newton. Observed and expected powder plug densities obtained by a capsule dosator nozzle system. *Int. J. Pharm.* 66:283–288 (1990) and references cited therein.
9. P. J. Woodhead. PhD Thesis, University of Nottingham (1980).
10. A. L. Window and G. S. Hollister. *Strain gauge technology*, Applied Science, Barking, 1982.
11. P. D. Huckle and M. P. Summers. The use of strain gauges for radial stress measurement during tableting. *J. Pharm. Pharmacol.* 37:722–725 (1985).