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RESEARCH PAPER

On the Accuracy of a New Displacement Instrumentation for Rotary Tablet Presses

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ABSTRACT

The Portable Press Analyzer™ (PPA; Puuman Oy, Finland), a commercially available instrumentation for rotary tablet presses, was tested for accuracy of determination of force and displacement. The calibration of the force transducers (strain gauges) was tested under a static condition. The calibration of the displacement transducers (plastic film potentiometer) was compared for static and dynamic recordings. Force measurement was found precise (deviation $<$ 1.1%) after alterations in the calibration procedure. Displacement measurement was affected by punch tilting and the application of the transducers. If tilting of punches was not considered, the deviation of displacement measurement from the true value (using steel tablets as a reference) was found up to 110 μm. By modifying the original PPA system by supplementing additional displacement transducers in the adjacent turret positions of the punches and adding a custom electronic device (Tilting Compensation Device), the accuracy of distance measurement was improved to 18.1 μm

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Dedicated to Professor Emeritus Dr. K. H. Bauer.

(±3.64). Furthermore, machine and tooling deformation were recorded and found different under static and dynamic conditions. Correction of punch displacement for elastic deformation therefore should preferably be made from dynamic recordings.

Key Words: *Accuracy; Instrumentation; Portable Press Analyzer™ (PPA); Rotary tablet press; Static and dynamic calibration.*

INTRODUCTION

The interpretation of displacement data of tableting excipients and drug substances during compression can help to optimize tablet formulation at a very early stage of product development (composition screening phase) and may allow the prediction of tableting requirements in order to achieve a robust composition and to avoid such problems during scale-up and production as capping, insufficient crushing strength, or low dissolution rates.

Differences in displacement readings during compaction caused by different deformation properties (elasticity, plasticity, brittleness) of tableting materials are very small (e.g., elastic recovery during the decompression phase reaches 50 to 230 μm for tablet heights about 3.5 mm) (dibasic calcium phosphate or pregelatinized starch, 5 to 25 kN). Therefore, high resolution and accuracy of the surveying system is most essential.

There are some effects that introduce an uncertainty in the dynamic measurement of tablet thickness: elastic deformation of the machine parts (punch/body) and tilting of the punches. Both effects are due to the tablet press construction, such as, the dimensions, clearances, and stiffness (elastic modulus of steel). In the literature, calculation methods (1,2–6) besides measuring methods (1,2,5,7) for elastic deformation can be found for rotary tablet presses. Nevertheless, little quantitative data has been published on the accuracy of displacement measurement for rotary compression systems. The resolution of the measurement system was mentioned by some authors (7,8).

This article gives such data for a rotary tablet press and an instrumentation system that is commercially available, the Portable Press Analyzer™ (PPA; Puuman Oy, Finland) (9). To evaluate the accuracy of displacement measurement on the rotary tablet press, steel tablets were ‘‘compressed.’’ Unexpectedly, a hysteresis during dynamic measurement of tablet thickness was observed with the original PPA, revealing the necessity to rework the instrumentation (Fig. 1). The alterations and improvements yielded are described in this paper.

MATERIALS AND METHODS

Machine

A Kilian Pharma RLA rotary tablet press (Nr. 45507-322, Kilian & Co. GmbH, Köln, Germany) was equipped at 1 of 16 stations with 9-mm Stokes B tooling (keyed) with a flat punch tip. A 1-3/16 brass die overlooking the die table was used, and blind dies were used at all other positions. The filling station and the runoff bar were removed completely, and the overload protection was fixed to 4 t. Force levels were set by moving the lower pressure roller with a handwheel. Filling depth was fixed at 10 mm. The tablet press was run at a speed of 21 rpm, 32 rpm, 40 rpm, or 42 rpm.

Data Recording and Instrumentation

Data acquisition was made by the Portable Press Analyzer™ Version 1.1, revision A (Puuman Oy, Kuopio, Finland), an infrared (IR) telemetric device with 16-bit analog-to-digital (A/D) converter (6 kHz). Upper and lower punch data were recorded and transmitted on separate channels by individual amplifiers (‘‘Boomerangs’’). The amplifiers truncated the raw data from 16 bit to 12 bit after measuring to check IR transmission (inserting control sums). The receiving unit (‘‘relay board’’) was connected to a personal computer (PC) (IBM PS/2 Model 80) via RS-232 (Fig. 2). The following data were recorded: round time, contact time, upper punch force and displacement during main compression, lower punch force and displacement during main compression and eject phase, tablet thickness (no precompression). Data were handled with Origin 4.0™ (Microcal Software, Inc., Northampton) and Statgraphics 7.0™ (Manugistics, Inc., Rockville, MD).

Forces were measured by strain gauges at upper and lower punches (DMS LG11-3, 350 Ω, full Wheatstone bridge; HBM Schweiz AG, Nänikon, Switzerland). Displacement of each punch was monitored by one or two plastic film potentiometers (Midori LP-10 and 20 FQ series, Pewatron AG, Switzerland). The supplier of the in-

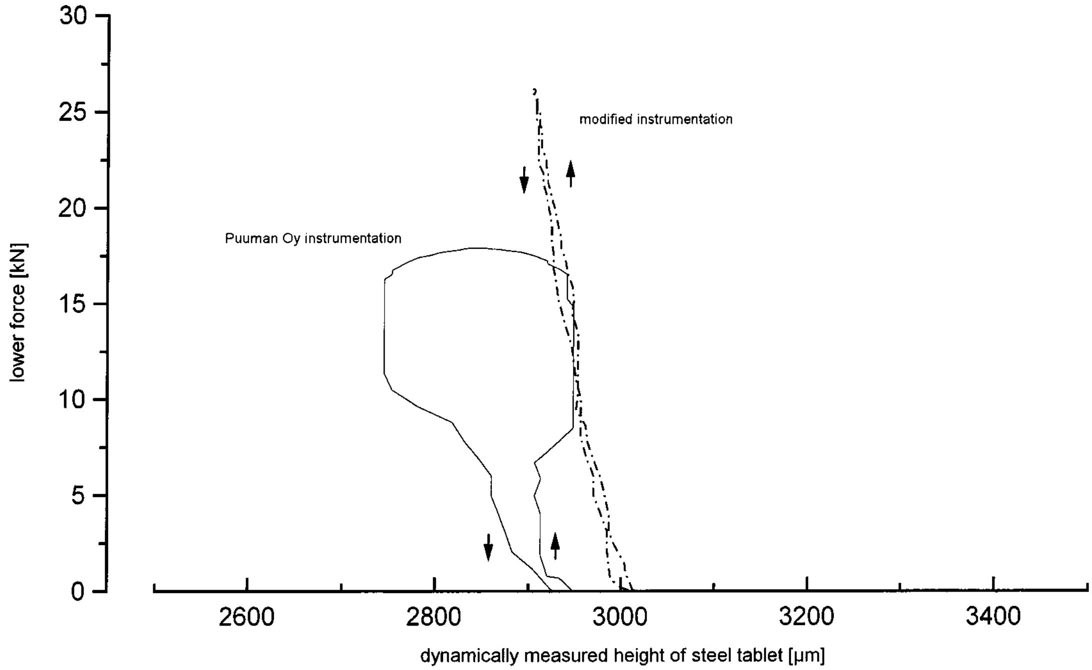

Figure 1. Comparison of original and modified instrumentation for a punch-to-punch compression with a steel tablet; ↑ = ascending force; ↓ = descending force.

strumentation system (Puuman Oy, Kuopio, Finland) originally connected the upper punch bridge to the punch head using one displacement transducer per punch (Fig. 2). The modified construction of the upper punch bridge, using two potentiometers, was fixed to the punch barrel as close as possible to the punch tip. The displacement transducers were installed with their movable cores toward the die table so a spring could be avoided (Fig. 3). For the lower punch, a similar bridge was installed.

The resolution of the force transducers was 15 N and 3 µm to 5 µm for the displacement transducers (10 mm at upper punch and 20 mm at lower punch), with background noise 45 N and 3 µm and 5 µm, respectively.

Calibration of Force Sensors

The force sensors were statically calibrated in the calibration unit supplied with the PPA system. The punch was positioned vertically and fixed at the punch head, while the punch tip was inserted in a regular 1-3/16 die. Load was given on the punch by a manually operated hydraulic cylinder and was raised in steps of about 2 kN ($r^2 > .999702$; 0–20 kN; 10 data points).

To check the calibration, the data of the reference load cell were compared with the measured force result from the PPA software working in normal measurement mode. Originally, corresponding steel inserts were placed between the punch tip and the reference cell (type C9A, 20 kN, HBM Darmstadt, Germany) to simulate the upper or lower punch position in the die during tableting. The inserts were found to cause low precision in force measurement (residual: 5%). Without inserts (i.e., with direct contact of punch tip and reference cell during calibration), the precision in force measurement improved to 0.1–1.1%.

Upper and lower punch force data were compared for a punch-to-punch compression cycle with steel tablets on the running tablet press (21 rpm) and differed slightly (0.1–1.1%).

Calibration of Displacement Sensors

Two displacement transducers were calibrated simultaneously using a micrometer screw (Mitutoyo, Code No. 164161, 0 to 50 mm, 0.001 mm, Tokoyo, Japan) in steps of either 330 µm ($r^2 > .9999868$: 0–10 mm) or 660 µm ($r^2 > .9999431$; 0–20 mm) and 30 data points each. The calibration of a single displacement transducer at a time led to comparable results ($r^2 > .9999$).

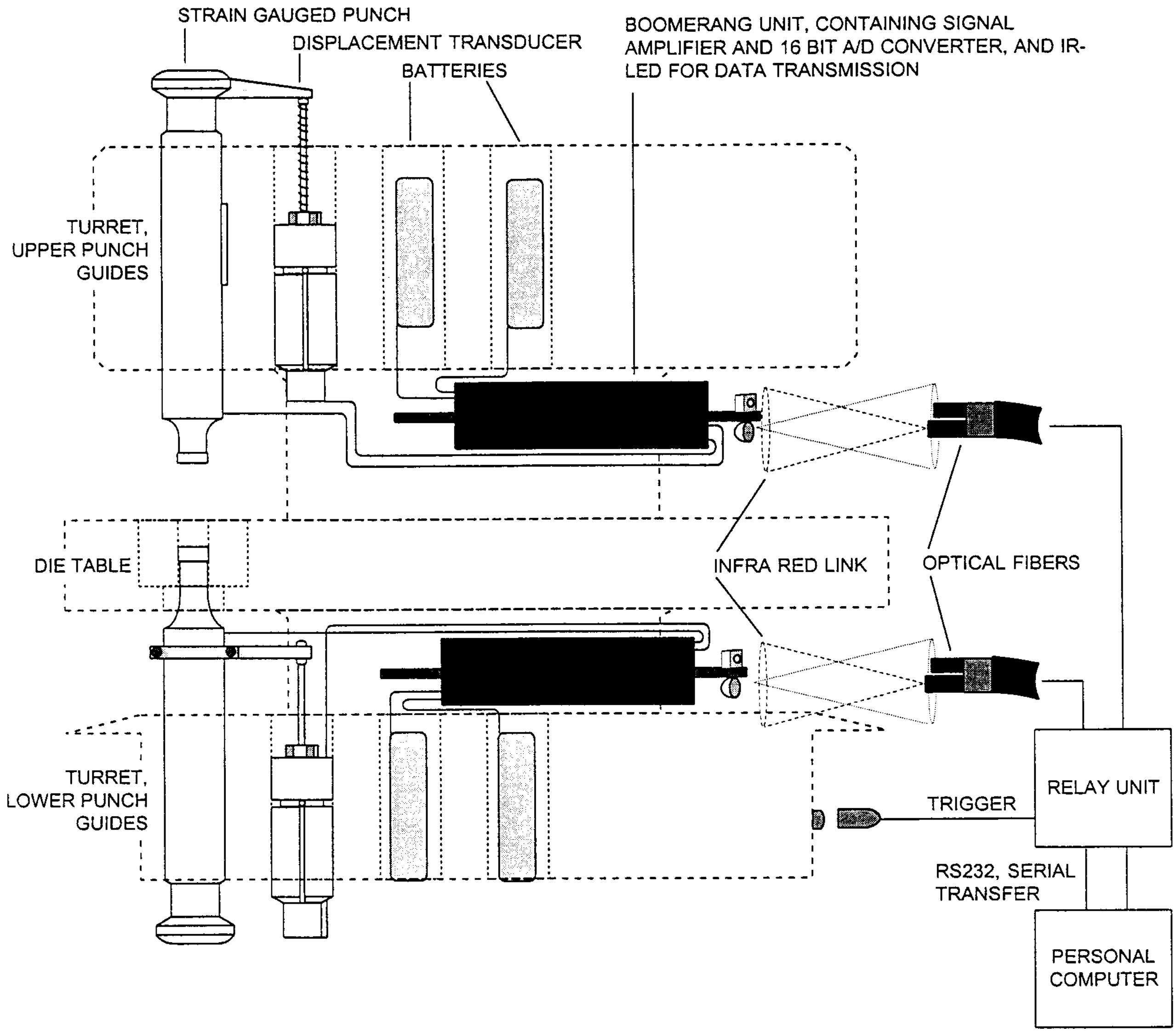

Figure 2. Schematic view of the PPA instrumentation system donated by Puuman OY, Kuopio, Finland.

Determination of Punch Tilting, Accuracy of Displacement Measurement, and Tablet Press Deformation

Hardened steel disks (flat faced, bevel edged) were used as a reference and for punch-to-punch compression runs. The height of the steel tablets was measured with the micrometer screw already used for calibrating the displacement transducers: Tablet A height was 3.711 mm (SD 0.0005; $n = 20$), with $D = 8.850$ mm; Tablet B height was 3.033 mm (SD 0.0004; $n = 20$), with $D = 8.940$ mm.

The runoff bar and the filling station were removed, and a die that overlooked the die table was inserted. If the sizes of the steel disks correspond to the commonly aimed tablet height for the tooling, the accuracy will be valid over the whole force and displacement range. Limitations of the method are press speed and weight of the steel disk as it needs time to fall back on the lower punch tip after the ejection phase. If it tilts and gets stuck during this movement, tooling may be damaged. Other tablet or punch tip profiles besides flat-faced shapes might be unsuitable for an investigation of dynamic machine deformation.

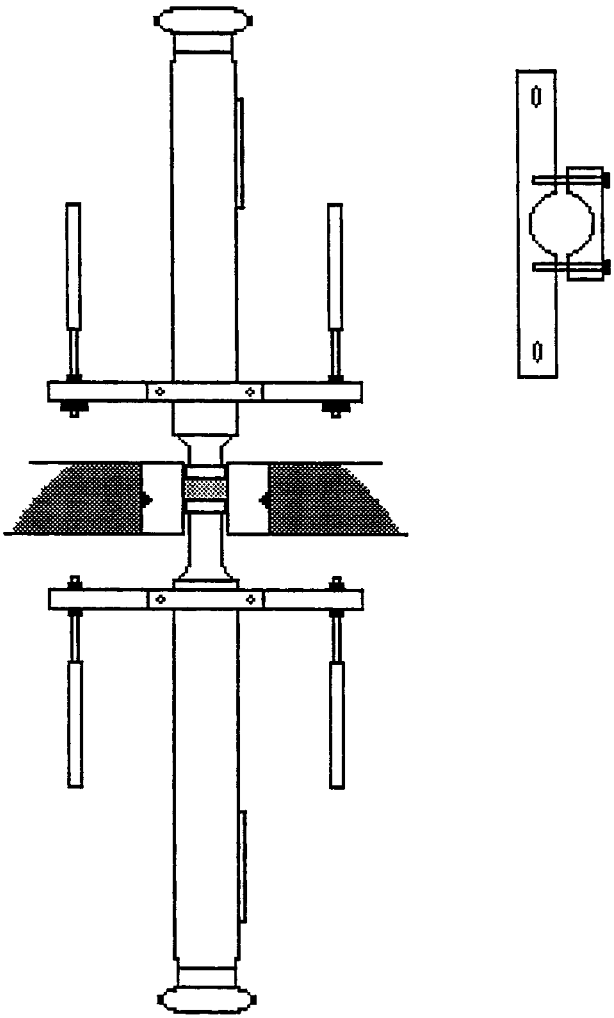

Figure 3. Application of displacement transducers and modified bridge construction.

Measurement of Tilting of Punches

For quantification of punch tilting displacement, transducers were inserted beside the punch in the preceding and succeeding punch holes. The reference point of the displacement transducers of both punches was set by manually pushing the punches together and against the upper pressure roller. A difference in data of left and right plastic film potentiometers attributed to punch tilting (Fig. 4). Permanent tilting caused by frictional resistance between punch head and turret or guidance was set as baseline for the evaluation of distinct tilting phases.

First, the displacement curves of left and right potentiometer of either upper or lower punch were recorded separately. Second, for all other investigations, the tilting was compensated for each punch individually and simultaneously by summing and averaging the voltage output of the left and right potentiometers. This was done electronically with a self-constructed unit called the tilting compensation device (TCD). The mean voltages then were fed to the corresponding ‘‘boomerang.’’

Accuracy of Displacement Measurement

The accuracy of displacement measurement was taken by comparing the known height of steel tablets with the measured data under static and dynamic conditions. Measurements were made with one displacement transducer, positioned either on the left-hand or right hand side, and using the TCD.

Static Method

The punches were placed in three positions under the pressure roller with a steel tablet and then were pushed together manually (Fig. 5a) so that no force was given on the punches. Both steel tablets were investigated (Tablet A and Tablet B).

Dynamic Method

The tablet press speed was fixed to 21 rpm, 32 rpm, or 42 rpm. Filling depth was set to 10 mm, and the applied force was adjusted to about 28 kN during punch-to-punch compression cycles with a steel tablet (Tablet A and Tablet B).

To compare the accuracy of dynamic measurement under load with the accuracy of static without load, the last value of dynamic tablet height, before the force increased, and the first value of dynamic tablet height, when the force reached the baseline again, were regarded.

Deformation Measurement

Punch-to-punch compression cycles with the steel tablets (Tablet A and Tablet B) were run. The deformation of the tablet press including punches was calculated as the difference between the last measured tablet height before the start of force and the reading of the displacement transducer under the given maximum load. This method avoided an influence of floating zero. It is used for static and dynamic investigations.

Static Method

The punches were placed under the pressure roller corresponding to position 2 (see Fig. 5a), and force was in-

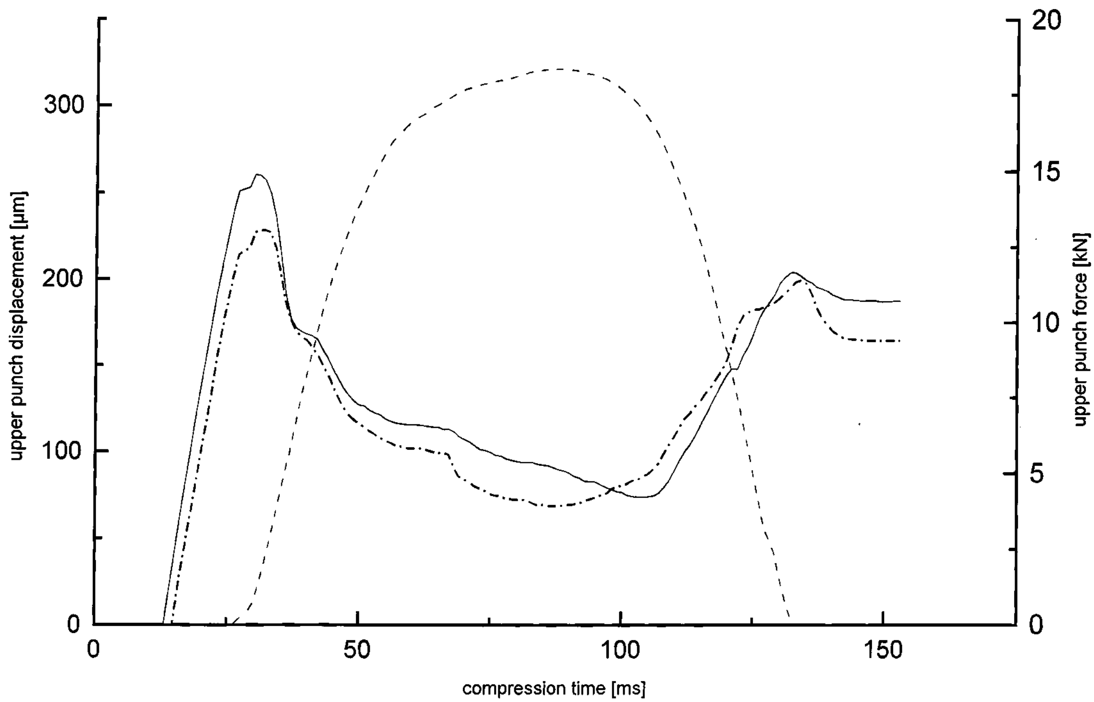

Figure 4. Upper punch tilting during a steel tablet compression: —— = displacement transducer on the right-hand side; -.-.- = displacement transducer on the left-hand side; --- = upper punch force.

creased and decreased by operating the lower pressure roller in 50 steps. The time intervall between measurements was 1 min.

Dynamic Method

The tablet press speed was kept to 21 rpm, 32 rpm, or 42 rpm. Filling depth was set to 10 mm, and the applied force was adjusted to about 28 kN.

Deformation of Upper and Lower Tooling

Deformation of upper and lower tooling was expressed as percentage of total deformation.

Calculation of Theoretical Punch Deformation

The dimensions of Stokes B type punches were taken from the literature (10). To facilitate the calculation, the punch was divided into three parts: head, barrel, and stem. The proportions in deformation were summed to the total deformation of the punch. The elastic modulus of the steel in use was set to 218 kN/mm^2. The maximum upper and lower force from static deformation tests (Table 1; lower force not shown) was used for the calculation.

$$(\Delta/l) = (F/A) \times (1/E) \quad (1)$$

where
Δl = deformation (mm)
l = length of investigated part (mm)
F = applied force (kN)
A = area of investigated part (mm^2)
E = elastic modulus = 218 (kN/mm^2)

RESULTS

Accuracy of Tablet Height Measurement with Either Left-Hand or Right-Hand Side Displacement Transducer

With separate left-hand (L) or right-hand (R) side positioned plastic film potentiometers, the accuracy of displacement measurement at the start of force was measured as listed in Table 2.

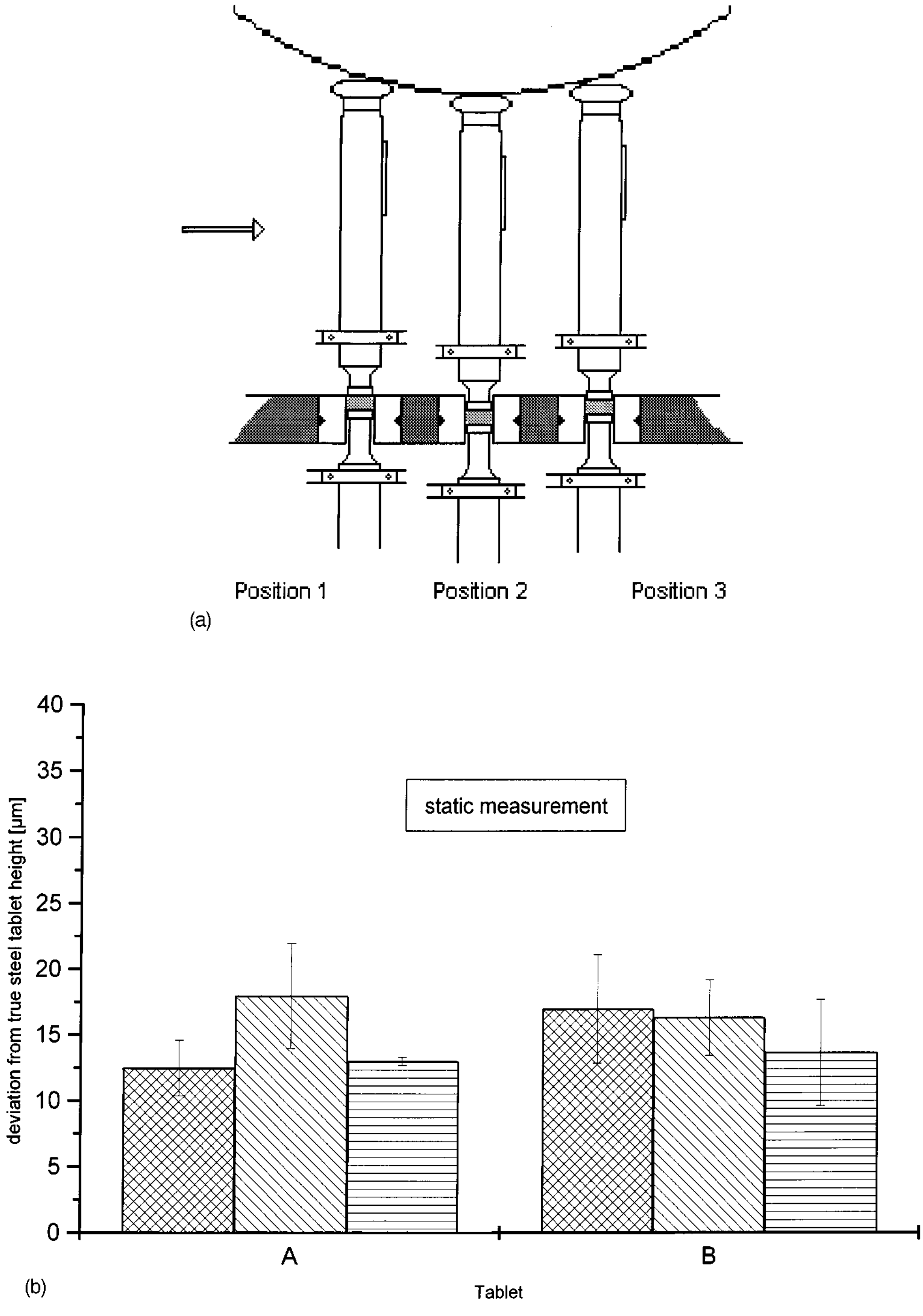

Figure 5. (a) Schematic view of punch position during static measurements for accuracy of displacement. (b) Accuracy of static tablet height measurement for positions in Fig. 5a: XXX = position 1; \\\\\\ = position 2; — = position 3.

Table 1

Machine and Tooling Deformation During Static and Dynamic Punch-to-Punch Compression

	Tablet A		Tablet B	
Tablet Press Speed (rpm)	Maximum Upper Force (kN) (SD)[a]	Deformation (μm) (SD)	Maximum Upper Force (kN) (SD)[a]	Deformation (μm) (SD)
Static	27.670 (0.002)	104.3 (6.8)	27.651 (0.027)	108.7 (4.5)
21	27.574 (0.308)	121.5 (1.56)	27.655 (0.207)	119.4 (2.88)
31	27.748 (0.151)	130.2 (2.77)	27.489 (0.390)	131.0 (1.58)
42	27.717 (0.366)	131.2 (2.19)	27.803 (0.258)	130.6 (4.04)

[a] Static: Tablet A, $n = 5$; Tablet B, $n = 11$; dynamic, $n = 5$.

Differences between most of the static and dynamic measurements showed no systematically caused deviations. The displacement transducer on the right-hand side (preceding) led to significantly lower accuracy compared to the left side, except for Tablet A at 40 rpm ($\alpha = 0.05$).

Tilting of Punches

Tilting occurred when the punches stepped on or off the pressure rollers and also shortly after the maximum compression force was reached (Fig. 4). The frictional resistance between the inside head angle of the punch and the turret led to small permanent tilting, and the curves were parallel. Areas of distinct tilting can be seen where the displacement curves cross each other.

The tilting of the upper punch may cause a maximum deviation in upper punch displacement measurement of 75 μm (steel tablet). Doubling of the press velocity (to 42 rpm) influenced neither the tilting direction nor the magnitude of tilting during the compression phase.

For the lower punch, a smaller maximum tilting of 45 μm was measured (not shown), resulting in a total residual of tablet height measurement of about 120 μm.

Accuracy of Static and Dynamic Tablet Height Measurement with Two Displacement Transducers per Punch

Figure 5b shows the results of the accuracy for static measurements when pushing the punches together manually on three different punch positions within the die (see Fig. 5a for positioning) and with two different steel tablets. The deviations from true steel tablet height were all in the range 13 to 18 μm with no significant difference ($\alpha = 0.05$).

Figure 6 describes dynamic tablet height determinations with the two steel tablets at two press velocities. Their maximum deviations from true value at start of force, 14 to 22 μm, were comparable to the static condition. Also, if the dynamic results were compared with the static data in position 2 (Fig. 5a) for Tablets A and B, the means were not significantly different ($\alpha = 0.05$).

Table 2

Deviation from True Height of Steel Tablet (μm) (SD)[a] During the Separate Use of Left- and Right-Positioned Displacement Transducer

	Left Position (Succeeding)			Right Position (Preceding)		
	Static	21 rpm	40 rpm	Static	21 rpm	40 rpm
Tablet A	40 (11.4)	78.8 (2.0)	75.6 (11.0)	100 (0)	108 (4.8)	66.7 (4.6)
Tablet B	44.1 (8.3)	47.7 (3.3)	37.1 (5.7)	86.8 (0.6)	108.3 (23.2)	117.3 (28.6)

[a] Static: $n = 10$ (left); $n = 15$ (right); 21 rpm, $n = 10$; 40 rpm, $n = 9$.

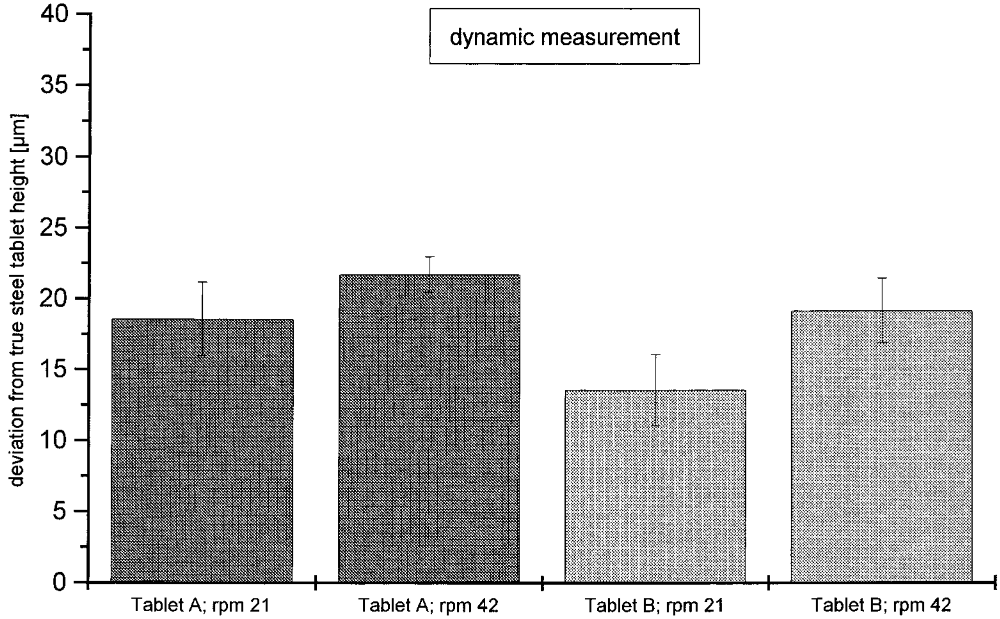

Figure 6. Accuracy of dynamic tablet height measurement.

The means of dynamic accuracy data were not significantly different from each other except for Tablet B at 21 rpm ($\alpha = 0.05$), which was found smaller than the others.

Tablet press speed had no influence on the accuracy of displacement measurement for Tablets A and B.

Static and Dynamic Deformation During Punch-to-Punch Measurements

The static punch-to-punch compression tests with Tablet A led to the deformation force curve shown in Fig. 7. The slope below 2.5 kN was steeper than after this point for both tablets investigated (Tablet B not shown). Above a force of about 2.5 kN, the plot became linear ($r^2 = .98$), thus indicating elastic deformation behavior of the machine and tooling. The slope was found to be 3.04 µm/kN (intercept 21.17) using Tablet A and 3.51 µm/kN (intercept 10.72) using Tablet B. The deformations of ascending and descending segments showed no significant difference ($\alpha = 0.05$), but there was a trend to smaller deformation on the descending part.

The deformation found by the dynamic method on the running tablet press is shown in Figs. 8a and 8b. Below 20 kN, the plots were almost linear and similar to Fig. 7, although the direction of the ascending and descending parts of the graph reversed. Above 20 kN, a hysteresis between the rising and descending part of the force/deformation plot was found, and the difference in deformation was not seen to be greater than 40 µm. At the three velocities studied, the force/deformation curves were similiar to each other.

Calculating the mean of all curves shown in Figs. 8a and 8b came to the following regression result: slope, 4.39 µm/kN; intercept 4.5; $r^2 = .99696$.

Table 1 quantifies the machine and tooling deformation at about 27 kN under static punch compression and also describes deformation at force maximum during punch-to-punch compression cycles on the running tablet press. If the deformations using Tablets A and B were compared, all the means showed no significant difference at the $\alpha = 0.05$ level regardless of compression conditions used. Static deformation was significantly lower than dynamic deformation ($\alpha = 0.05$). The mean deformation for 21 rpm was significantly smaller than at the 32 rpm and 42 rpm conditons ($\alpha = 0.05$).

Distribution of the Deformation Between Upper and Lower Tooling

Table 3 compares the proportion of deformation of upper and lower punch for static and dynamic deforma-

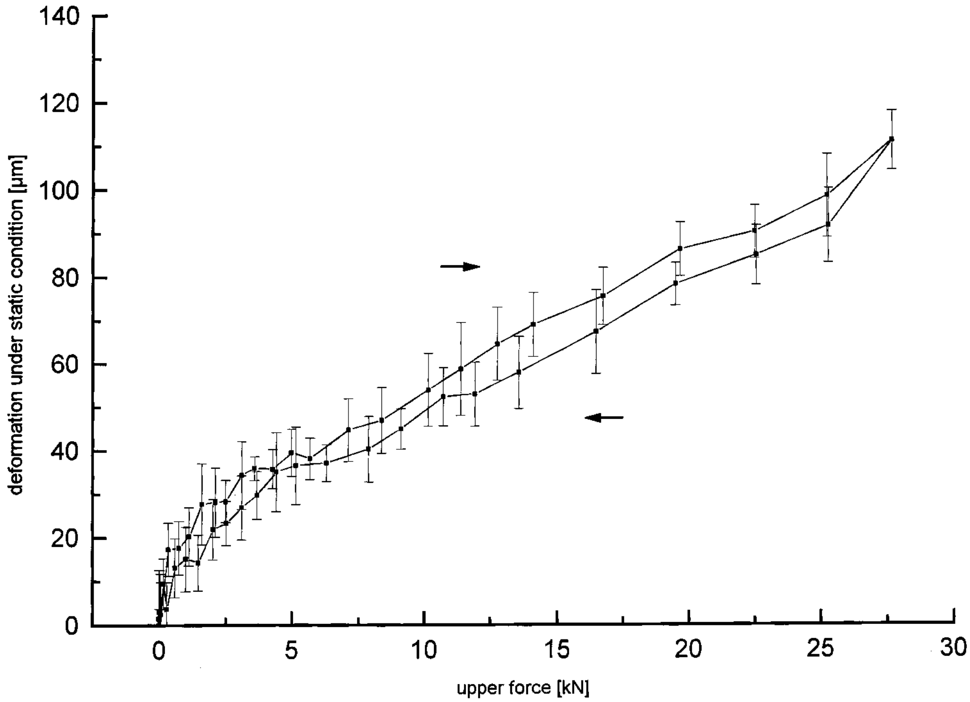

Figure 7. Tablet press deformation during punch-to-punch compression with Tablet A under the static condition ($n = 5$): → = ascending force; ← = descending force.

tion behavior during punch-to-punch compression with steel tablets.

It was found that deformation of the lower punch was larger under the static condition. On the running tablet press, the upper punch unit (punch, pressure roller, and frame) experienced greater deformation. A slight tendency to greater deformation of the upper punch with increasing press speed may be seen only for Tablet A ($\alpha = 0.05$).

The various heights of the steel tablets had no influence in the proportion of deformation between the upper and lower punch (except for the 21 rpm condition).

Comparison of Measured and Theoretical Punch Deformation

The investigation was done with tablet A and can be seen in Table 4 (force 27.6 kN; $n = 5$). The extent of deformation between the calculated and measured (static or dynamic) investigations differed significantly, whereas the percentage in deformation of upper and lower punch was similar for the theoretical and static conditions.

The deformation of tablet A itself, calculated under the given condition, was 7.6 µm, also assuming an elastic modulus of $E = 218$ kN/mm^2.

Accuracy of Displacement Measurement at Beginning and End of Force

The accuracy of displacement determinations at the start and end of force for dynamic punch-to-punch measurements with steel tablets was compared (Table 5). There was no significant difference for tablet height measurements between the values of the ascending and descending sides at the force baseline, except for tablet A at 42 rpm ($\alpha = 0.05$), although ‘‘end values‘‘ were always higher.

Precision Comparison of Original and Reworked Instrumentation

Figure 1 shows typical force/displacement plots of steel tablet compressions for both systems. For the original (Puuman OY) instrumentation, a maximum differ-

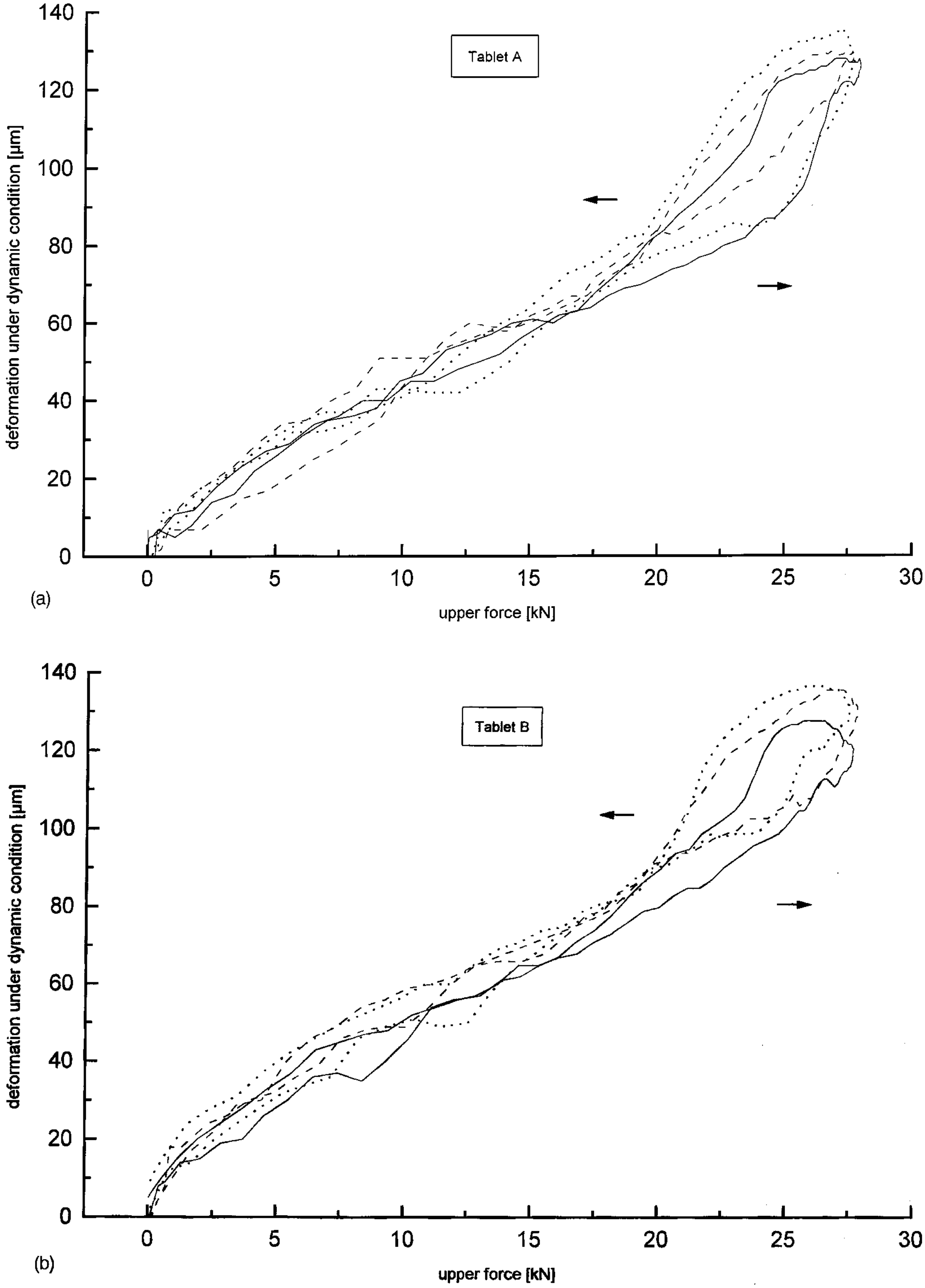

Figure 8. (a) Tablet press deformation during punch-to-punch compression with Tablet A under dynamic condition ($n = 5$): — = 21 rpm; ···· = 32 rpm; -- = 42 rpm; → = ascending force; ← = descending force. (b) Tablet press deformation during punch-to-punch compression with Tablet B under dynamic condition ($n = 5$): — = 21 rpm; ···· = 32 rpm; -- = 42 rpm; → = ascending force; ← = descending force.

Table 3

Distribution (%) SD[a] of the Deformation on the Upper and Lower Punch

	Tablet A		Tablet B	
Measurement Condition	Upper Punch	Lower Punch	Upper Punch	Lower Punch
Static	40.8 (0.51)	59.2	41.3 (0.69)	58.7
21 rpm	73.9 (0.57)	26.1	76.0 (1.05)	24.0
32 rpm	75.6 (0.79)	24.4	77.6 (2.23)	22.4
42 rpm	79.1 (1.98)	20.8	78.2 (2.94)	21.8

[a] See footnote to Table 2.

Table 4

Comparison of Calculated and Measured Deformation of the Stokes B Punches with Tablet A

	Total Deformation (μm) (SD)[a]	Distribution of Deformation (%) (SD)	
		Upper Punch	Lower Punch
Calculated	167.4	41.8	58.2
Measured/static condition	104.2 (6.8)	40.8 (0.51)	59.2
Measured/dynamic condition (21 rpm)	121.5 (1.56)	73.9 (0.57)	26.1

[a] Force = 27.6 kN; static, $n = 5$; dynamic, $n = 5$.

Table 5

Comparing Accuracy of Displacement Measurement at Beginning and End of Force (μm) (SD)[a]

	Tablet A		Tablet B	
	21 rpm	42 rpm	21 rpm	42 rpm
Beginning of force	18.6 (2.6)	21.75 (1.25)	13.6 (2.5)	19.2 (2.28)
End of force	27 (8.48)	28 (3.55)	14.8 (3.7)	23 (7.31)

[a] $n = 5$.

ence of 202 μm was found between the ascending and descending parts of the force/displacement graph. At the beginning and end of force, there was a difference in displacement of 72 μm. In the example shown, the maximum force applied was 17.917 kN at a press speed of 33.4 rpm.

Even if the machine was run at a higher press speed (42 rpm) and to a higher maximum force (26.185 kN) using the modified instrumentation, the maximum difference between the ascending and descending sides was 18 μm and 3 μm at the start and end of force, respectively.

DISCUSSION

Application of Displacement Transducers

Working on a reciprocating tablet press, Ho et al. (11) concluded that, for accurate punch travel measurement, the displacement transducer has to be placed close to the punch. Watt and Rue (12) installed displacement transducers in extra holes of the turret of a Manesty Betapress so the actuator arm for the movable LVDT core could be kept very short, and tilting transfer to the transducer would be smaller. Methods for collecting displacement data of a punch by separate measurements by exchanging the transducer between the leading and trailing positions then unifying the data also are reported for tilting diminution in the literature (1). This method is assumed to be less accurate than collecting the data simultaneously, as realized by Heikamp (7) with the application of two transducers in the adjacent punch holes between two punches of a rotary tablet press, but continuous operation was not possible. The most commonly used method of application is to insert the potentiometers in the leading or trailing punch guides as done for the modified PPA system.

Punch Tilting

Figure 1 is an example for a steel tablet compression recorded with the original PPA. Despite the moderate compression conditions, the original force/displacement plot showed an unexpected difference between the ascending and descending sides and at the force baseline (Fig. 1). The reason is in the bridge construction, the use of a spring (for keeping contact between the transducer core and the bridge), and the use of only one displacement transducer.

After alterations in the bridge construction and in the application of displacement transducers (Figs. 2 and 3), the accuracy of tablet height measurement with one transducer still showed differences between static and dynamic recordings (Table 2) and between the leading and succeeding positions. The resulting residual in tablet height determination, caused by punch tilting, would be about 120 μm. The size of this deviation (about 3% regarding height of steel tablet) verified that tilting of punches had to be considered for accurate displacement recording on rotary tablet presses. Oates and Mitchell (1) reported deviations in work of compaction based on the displacement data of an LVDT in the trailing position and the displacement data from a tilting compensation method (4% to 21%, depending on substance and punch type). The present results for tilting were also in the same range as the data of Schmidt and Tenter (13) (about 100 μm) using two displacement transducers in the adjacent positions of the turret for a Fette P2 rotary tablet press with Parmcompress™ (dibasic calcium phosphate dihydrate). Heikamp (7) investigated punch tilting during the compression of maize starch tablets with a similar construction on a Fette Hanseaten Perfecta P1 with a double-compression technique. He found a smaller deviation of displacement data (approximately 24 μm).

Using two displacement transducers per punch simultaneously, the accuracy of displacement measurement improved to approximately 18 μm, and no difference between static and dynamic measurements were found. Furthermore, measurement of tablet height (at start and end of force of a compression cycle) was widely independent of press speed (Table 5).

Elastic Deformation

The elastic deformation of rotary tablet presses was reported in the literature as a source of deviation in displacement measurement. Some authors only mentioned the problem (8,12–14), and other groups gave detailed descriptions (3,5–7,15). Oates and Mitchell (1,2) compared a calculation and measuring method for punch displacement combined with the results of experimentally gained machine deformation under static and dynamic conditions on a Manesty Betapress. Compressing three excipients of well-known compaction behavior, they found that large residuals (approximately 8% to 26%) would occur in calculating punch displacement if machine deflection under dynamic conditions is not taken into account. Another dynamic determination of elastic machine deformation was done by Heikamp (7), who ran a punch-to-punch compression cycle and found 120-μm machine deflection at a pressure of about 60 MPa (6.8 kN). Atlaf and Hoag (5) used a cathetometer to survey reference marks on the punches of a Stokes B2 rotary tablet press. To measure press deflection, they compressed rubber plugs and lead and found 440-μm press deformation at 250 MPa (17.8 kN). Some groups reported static measurement techniques for press deformation that were used to correct calculated punch displacement; for instance, Schmidt and Vogel (3) reported punch-to-punch measurements on a Korsch PH 230 and found different slopes for the deformation plot below and above 2.5 kN (above 2.5 kN: 24.4 μm/kN). More recently, Leitritz (6) measured the deformation at the same press using a micrometer gauge mounted between the machine body and roller pin and found comparable results (above 2.5 kN: 22.7 μm/kN).

Changes in the slope of the deformation/force plots in the range of 2.5 kN as found by Schmidt and Vogel (3) were reported by other authors as well (1,2,6). A similar shape of deflection/force plots could be seen in the present results (Figs. 7, 8a, and 8b). The reason for nonlinearity below 2.5 kN can be seen in looseness between the pressure roller and roller pin and/or between the handwheel for changing tablet height and the lower roller support. These tolerances of the bearings are used first when vertical force is applied, thus showing higher slopes in deformation/force graphs. The positions of the ascending and descending parts of the graph reversed between the static and dynamic conditions. Above 20 kN, a hysteresis between the rising and descending parts of the force/deformation plot was found for the dynamic conditions and was not seen to be greater than 40 μm.

A significant difference ($\alpha = 0.05$) between the extent of static and dynamic tablet press deformation at maximum forces of about 27.6 kN (Table 1) was found. Static deformation was smaller than dynamic deformation. Depending on press speed, the proportion of deformation between upper and lower punch changed. The total deformation was also affected by machine speed. Therefore, dynamic deformation should always be measured.

CONCLUSION

The Portable Press Analyzer™ (Puuman Oy, Kuopio, Finland) appeared to be a useful device for the instrumentation of a rotary tablet press only after substantial alterations. Modifications in the calibration procedure of the force transducers led to an acceptable precision concerning force measurements (0.1% to 1.1%). Investigations into accuracy of displacement measurement revealed the necessity to compensate for punch tilting using additional transducers and modifying their application.

Elastic deformation of the tablet press was influenced by machine speed. Therefore, machine deformation must be measured dynamically in order to correct displacement measurement on rotary tablet presses, as did Oates and Mitchell in 1989 (1,2). The accuracy of displacement measurement was 18.1 μm (± 3.64), which is comparable to the accuracy of distance measurement on single-punch tablet presses (16,17).

The *modified* PPA proved suitable for the dynamic calibration and measurement of punch displacement on a rotary tablet press. It also appears to be useful for dynamic calibration of force measurement on such machines.

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