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A COMPARISON OF THREE METHODS OF ESTIMATING DISPLACEMENT ON AN INSTRUMENTED SINGLE PUNCH MACHINE.

Angel Muñoz-Ruiz[*1], Rafael Gallego[**], Manuel del Pozo[**], Mª Rosa Jiménez-Castellanos[*] and José Domínguez-Abascal[**]

* Dpto. de Farmacia y Tecnología Farmacéutica. Facultad de Farmacia. C/ Tramontana S/N. Sevilla 41012. SPAIN.

** Cátedra de Estructuras. Escuela Superior de Ingenieros Industriales. Avda Reina Mercedes S/N. Sevilla 41012. SPAIN.

ABSTRACT

In this paper a determination of the possible sources of experimental errors of displacement measurements by an instrumented single-punch machine and their repercussion in compression parameters has been accomplished. Also, elastic deformation of punches and other parts of the machine was evaluated using three different methods. One of these, based on the strain gauge response as measure of punch deformation it is proposed as a novel method to correct displacement measurements by instrumented machines.

INTRODUCTION

For the first time in pharmacy Higuchi and his coworkers (1), introduced a system for measuring displacement of the punch during the compression process (2). This was accomplished by means of an inductive displacement transducer mounted onto the upper punch system. Also, several authors (3, 4) have reported the instrumentation of tablet machines. In this way, De Blaey & Polderman (5) linked the displacement transducer unit (outer case) to the machine part holding the upper punch, but the essential inductive part (armature) was firmly linked to the lower punch. The most popular scheme usually followed in instrumentation (6) includes Linear Variable Displacement transducer (LVDT) with the armature and the outer case clamped to the punch holder and machine frame respectively. Also, Moldenhauer (7) commented the fact that the inductive transducer can be easily attached to the punch guide.

More recently, the displacement measurements were analyzed by comparison of three methods of mounting linear variable displacement transducer on an instrumented tablet machine (8), establishing empirical equations for the error in distance (9) or determining the accuracy and precision of powder height and punch displacement measurements (10). In this sense, a non-linear relationship between applied force and frame distortion had been observed, much earlier, by Shotton & Ganderton (11) which motivated them to develop strain-gauged punches for the measurements of the force.

At this moment, the theoretical estimations of punch displacement (12), dwell and consolidation times (13) on the basis the theoretical movement of the cam track or the calculation of the distance between punches including their elasticity coefficients to evaluate the height of the die (14) are been investigated.

EXPERIMENTAL

We assumed the same starting point that Juslin and Paronen (9). The greatest error in a distance measurement must be the looseness in machine (Bonals AMT 300, Oliverar 6, Barcelona, Spain) itself (frame distortion and fitting sets). This kind of error may be exist even. Secondly, errors must also be due to elastic deformation of the punches and other parts of the machine (punch holder). These errors become distinctive at relatively high compressional forces.

In the first place, in order to determine the frame distortion and fitting sets without load application one displacement transducer HBM W50-TS (HBM, Hottinger Baldwin Messtechnik, D-6100 Darmstad 1, Germany) with its two components joined to the punch holder and machine frame respectively and another displacement transducer close to the punch with the iron core positioned onto a special piece made for this calibration, was mounted (Figure 1). Signals from both transducer were monitored in a digital dynamic amplifiers HBM AB 12. The zero point signals were adjusted by offsetting the associated detector and amplifier. Values of displacement were obtained making the corrections of the signals with the AC-energized Linear Displacement

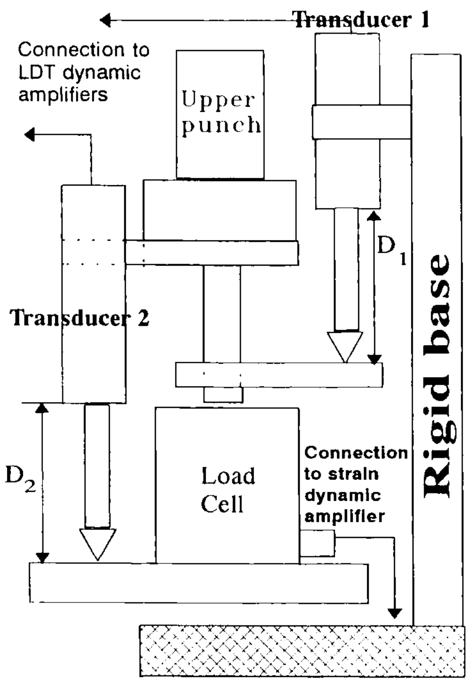

FIGURE 1
Mounting scheme of the LDTs.

Transducers (LDTs) output of 80 mV/V per mm in both transducers. Displacements measured with both transducers were similar being the correlation coefficient between two signals higher than 0.9999 and the slope of the linear regression equal to 1. These results demonstrated the non-existence of frame distortion and fitting sets. Error due to tilt was suppressed (15) flushing the outer case of the transducer with machine frame (± 0.02 degrees of accuracy).

In the second place, deformation of the punches and other parts of the machine was experimentally evaluated with the same mounting. In this case, pressure was applied with the punch on a calibration load cell Lebow 3764-5012 (Eaton, Corp., 1728 Maplelawn Road, Troy, Michigan 18084, USA) connected to strain dynamic amplifiers Nec San-ei 6M81 (NEC San-ei Instrument, Ltd. 12-1, Okubo 1-chome, Shinjuku-ku, Tokyo 160, Japan). The displacement measurements and the difference between both estimated displacements versus applied force may be seen in Figure 2 for the upper punch. Measured displacement by the transducer joined to the punch holder and machine frame was always higher than the one registered by the LDT attached to the punch end. This is due to the punch shortening which affects the second measurements whereas it does not influence the first one. Therefore, from the difference between these two measurements shortening may be computed. This effect may be expressed as a linear or non-linear relationship with applied force. The linear regression with a correlation coefficient of 0.9523 and a F-value of 725.2 is represented in Figure 2. Slope obtained was $8.0299 \bullet 10^{-5}$ mm/Kp with a standard error of $9.808 \cdot 10^{-6}$, the high error (12.21%) induced us to use an alternative method to correct the accuracy of displacement measurements. Also, polynomial, geometric and exponential regressions (9,12) were performed and low values of correlation coefficients were obtained. The high error in this method may be diminished using displacement transducers with less stroke and high accuracy, but different from the ones employed in the instrumentation. Furthermore, manual load application it is necessary to perform these measurements. Thus, this mounting proposed in Figure 1 is only suggested to check frame distortion and fitting sets.

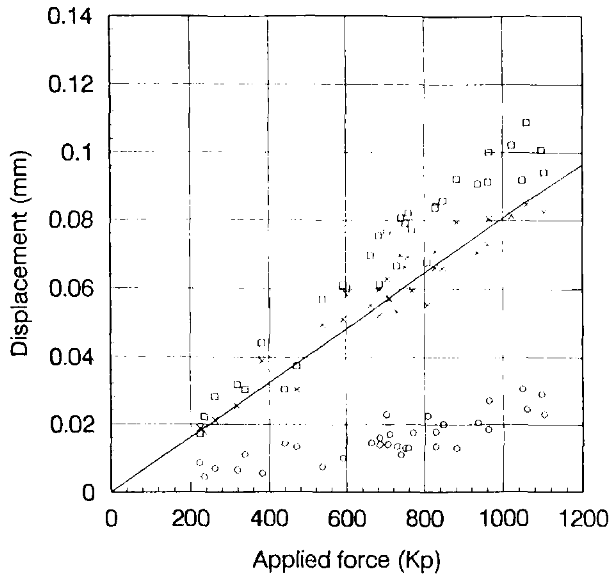

FIGURE 2
Displacements obtained with the two LDTs of Figure 1. Signal of transducer 1 (○) Signal of transducer 2 (□), Diference between signals (x), Linear regression of differences (-).

The second method was to calculate theoretically the relationship between punch applied force, and punch and other machine parts shortening on the basis of elasticity theory. The axial rigidity of a prismatic element is defined as the ratio between the axial force and the displacement it produces. This rigidity K is simply:

$$K = \frac{EA}{L}$$

where L is the length of the piece, A its area and E the Young's modulus of the material. When the prismatic element has sections with different areas, the total rigidity is computed from the sectional rigidities by the formula:

$$\frac{1}{K} = \sum_i \frac{1}{K_i}$$

The sectional areas of the upper punch are (see Figure 3, length in mm) AA' = 96.02 mm^2 and BB' = 115.94 mm^2. The former has been calculated by using the following equation,

$$A = \frac{1}{2} D^2 \arcsin\frac{H}{D} + \frac{1}{2}\sqrt{D^2 - L^2}$$

where L = length of sectional area and D = punch diameter. Given the Young's modulus of the upper punch (stainless steel, E = 2.1 10^{-4} Kp/mm^2) and its geometrical properties, the sectional rigidities are (in Tn/mm): $K_1 = 112$, $K_2 = 117$; therefore the total rigidity is K = 57 Tn/mm.

Hence the slope in a force-displacement representation would be 1.75 10^{-5} mm/Kp which is notably lower than the former experimental measure. Part of the difference could be accounted for by the fact that the punch holder deformability has been neglected in these calculations. However, this fact would only represent a small increase in the calculated slope.

The third method is based on the direct measure of the deformation by the strain gauge attached to the base of the punch. The deformation in the upper section which is given by the strain gauge is readily related to the total deformation of the punch.

Thus $\varepsilon_1 = \Delta l_1 / l_1$, then $\Delta l_1 = l_1\ \varepsilon_1$. But $F_1 = K_1\ \Delta l_1$ and, by equilibrium $F_2 = F_1 = F$ where F is the applied force. Therefore, the total elongation Δl is:

$$\Delta l = \Delta l_1 + \Delta l_2 = \Delta l_1 + \frac{F_2}{K_2} = \Delta l_1 + \frac{F_1}{K_2} = \Delta l_1 + \frac{K_1}{K_2}\Delta l_1$$

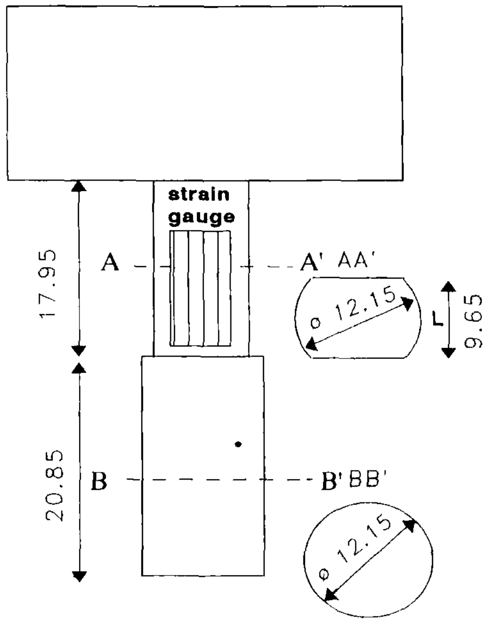

FIGURE 3
Upper punch geometry (length in mm).

and thus

The subscripts refer to the two different sections in the upper punch (see Figure

$$\Delta l = \left(1 + \frac{K_1}{K_2}\right) l_1 \varepsilon_1$$

3). Substitution of known properties of the upper punch yields, $\Delta l = 35.133\text{mm}\ \varepsilon_1$.

The two strain gauges fixed onto the section AA' of the upper punch (see figure 3) have the following characteristics: gauge factor (K = 2.0), bridge voltage set in 2V (NEC San-ei 6M81), gauge configuration = 2 (two active and two dummy gauges). Strain measurement with these gauges is done using the calibration value, that we set at 100 $\mu\varepsilon$ in the amplifier and the corresponding output voltage -calibration voltage-. With this configuration the output voltage for the calibration signal of 100 $\mu\varepsilon$ is 0.0802V.

A previous calibration of the force applied by the upper punch was performed using the load cell Lebow 3764-5012. The calibration obtained monitoring both signals in two channels of the dynamic strain amplifiers before mentioned, yields a ratio of 5.4844 between output voltage in channel of upper punch and output voltage in channel of the load cell. This ratio was calculated employing a linear regression between both output voltages. Correlation coefficient was 0.9999 and standard error in slope was $3.44\cdot10^{-3}$.

Thus, we can compute a relationship between applied force and the strain using the calibration of the force applied by the upper punch (5.4844 output voltage of punch channel/output voltage of load cell channel), the output of the load cell (131.31 Kp/output voltage of load cell channel) and the output voltage for the calibration signal (0.0802 output voltage of punch channel/$\mu\varepsilon$).

Therefore, based on the relationship between the applied force and the gauge measurement and substituting in the formula $\Delta l = 35.133\text{mm}\ \varepsilon_1$, the final ratio obtained is $1.83\cdot10^{-5}$ mm/Kp. This semiempirical value was consistent with the value obtained with the second method ($1.75\cdot10^{-5}$mm/Kp).

We must remark that the theoretical method is in very good agreement with this semiempirical method based on the calibration of the dynamic strain gauges attached to the punches with a load cell. In the semiempirical method a low standard error in the calibration of the force applied by the upper punch it is obtained, and therefore a low error of 0.06% in the estimation of punch shortening.

Like experiments and calculations were performed for the lower punch and similar results were obtained. In the first method a $9.03 \cdot 10^{-5}$ mm/Kp ratio with a standard error of $8.99 \cdot 10^{-6}$, in the second one $1.87 \cdot 10^{-5}$ mm/Kp and in the last one the ratio obtained was $2.10 \cdot 10^{-5}$ mm/Kp. The slope is greater due to the lower sections and the greater length of this punch.

In order to determine the error produced in Heckel parameters (16) using tablet-in-die Heckel plot (17) and defining the linear portion by the maximum correlation coefficient the data acquisition program for the Metrabyte DAS16-G1 A/D converter (Metrabyte Corp., 440 Myles Standish Blvd., Taunton, MA 02780, USA) was changed. In the routine -QuickBasic 4.5- (Table 1) which performs the conversion between digital output and physical magnitudes of the four channels (upper and lower punch forces and displacements) and writes the data to a temporary data file, two new variables were added (DTC3CF and DTC4CF, upper and lower punch displacements respectively), which store the value of the displacement taking into account the punch shortening. These modified displacements are the old ones minus the correction due to the forces from channels 1 and 2 (variables DTC1 and DTC2).

Figure 4 displays the differences between the Heckel plots of methods using Emcompress® -dicalcium phosphate dihydrate- (Mendell, Carmel, NY, USA). The yield pressure estimated with the correction of the punches shortening was 234.5 MPa and 229.1 MPa without it. The relative density

TABLE 1
Data reduction routine (Quickbasic 4.5) of force and displacements channels.

```
OPEN "DATATEM.DAT" FOR OUTPUT AS #1
  WRITE #1, NUDATA%, UL% + 1, SCT%, t
        FOR i = 4 TO (NUDATA% - (UL% * 2)) STEP UL% + 1
                        DTC1 = (5.2524312# * CALcelS / (AplS * A2S * ATTNpunS * ATTNcelS * VCAlcelS))
                        * (dt%(i) - ((ATTNpunS * A2S * BplS) + B2S))
                        PRINT #1, USING "######.###"; DTC1;
                        DTC2 = (5.2524312# * CALcelI / (AplI * A2I * ATTNpunI * ATTNcelI * VCAlcelI))
                        * (dt%(i + 1) - ((ATTNpunI * A2I * BplI) + B2I))
                        PRINT #1, USING "######.###"; DTC2;
                        DTC3 = ((dt%(i + 2) - (a3 * bt3) - b3) / (a3 * at3))
                        DTC3CF = DTC3 - (DTC1 * .0000183)
                        DTC3CFIO = DTC3CF - MMDESUO
                        PRINT #1, USING "#####.####"; DTC3CFIO;
                        DTC4 = ((dt%(i + 3) - (a4 * bt4) - b4) / (a4 * at4))
                        DTC4CF = DTC4 - (DTC2 * .000021)
                        DTC4CFIO = DTC4CF - MMDEINO
                        PRINT #1, USING "#####.####"; DTC4CFIO
        NEXT i
CLOSE #1
```

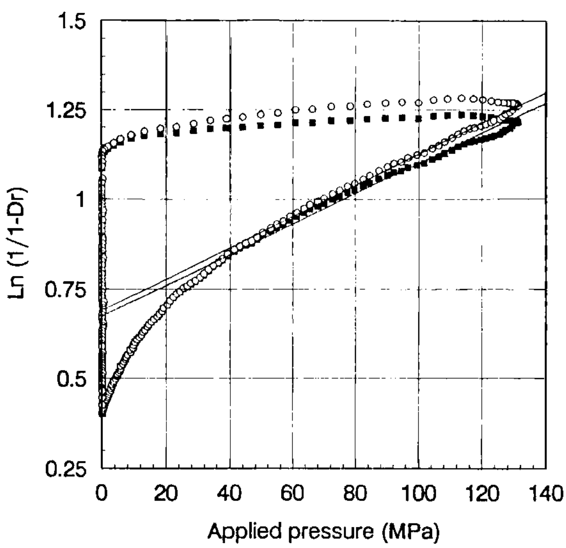

FIGURE 4
Heckel plots of Emcompress® (○) without and (■) with correction of displacements.

measurements obtained with the corrections are lower and therefore the value of the yield pressure computed using the corrected displacements were higher due to the deformation of the punches. In this case the experimental correction after removing this source of error is 2.24%. Higher errors will be obtain as applied pressure increases. This error, demonstrates the importance of computing punch deformation with the acquired data of applied forces (strain gauge response), when the displacements will be used in calculating compaction parameters.

CONCLUSIONS

Compression parameters computed using displacement measurements by instrumented tablet machine must be corrected taking into account the elastic deformation of the punches and other parts of the machine. A new semiempirical method based on the dynamic strain gauge response as measure of punch deformation it is proposed to correct the accuracy of displacement measurements.

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