10th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

ABOUT TOLERANCE ACHIEVEMENT IN ROTARY TABLE MACHINE

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ABSTRACT

An accurate angle positioning of rotary table is a common issue in contemporary machine industry. There are various solutions for this problem, but in order to achieve rigidity of the assembly and repeatability of the position, a mechanical system is often included for positioning and clamping.
The object of analysis presented in this paper is tablet manufacturing machine. Having in mind that it is an inexpensive machine, a simple mechanical system is chosen for location of the table. A driving device moves the table to approximate position, after which clamping device assures it precise location and locks it. Nevertheless a considerable precision has to be achieved.
The definition of measures and its tolerances is considered as the issue that has greatest impact on precision functioning of the assembly. Presented considerations regard to a specific machine design, but general conclusions can be drawn. Those can be seen as a part of the machine documentation revision process in which precision is lifted to the highest level, without changing the main solution characteristics.

Keywords: Precision, tolerance, rotary table machine

1. PROBLEM DESCRIPTION

1.1. Working assembly functioning

The main part of working assembly (Fig. 1) is a rotary turning table (1) with 16 seats (2) that are filled with tablet material. Tablet forming is a 4 stage process, so 4 tablets are made simultaneously. The material is moved from one stage to another by table rotation. The most important stage is pressing, when molding tool (3) enters the seat and forms the tablet. Positioning precision of individual seat according to every of 4 tools is the main functional characteristic of the assembly.

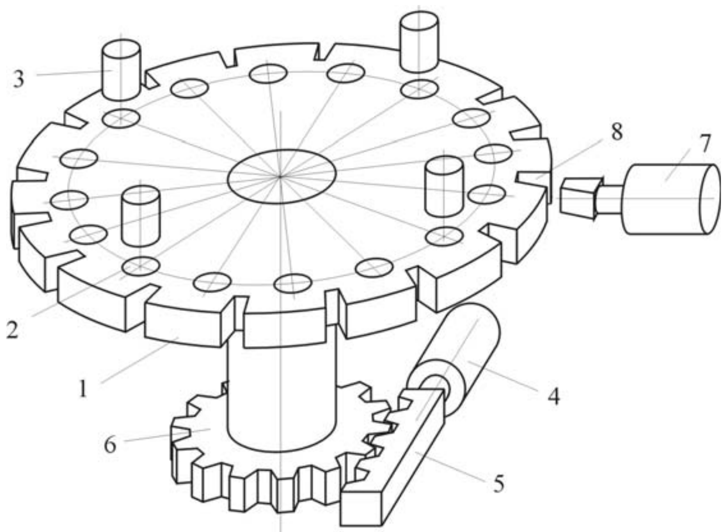

Figure 1. Working assembly

Table rotation is achieved by rotation device that consists of a cylinder (4) with gear bar (5) connected with gear (6), which is connected to table carrier by one-way clutch. Positioning of the table is assured by clamping device

that has a clamper (7) which enters slots (8) at the edge of the table.
It is important that tools and clampers has some positioning allowance that enables them to be set according to prime seats and slot at the assembly process. In this way, it is not the positioning of the clamper and tools according to the frame that defines the precision during the working process, but mutual position of seats and slots on the table.

1.2. Precision definition

It is said before that position of the clamper and tools are defined according to prime table position, i.e. position of prime seat (B_1) and slot (A_1). After the rotation, the table will stop when clamper inserts to the next slot (A_2). In that moment the next seat (B_2) will reach position under the tool. The difference between points B_1 and B_2 (B_i) defines the working precision (see Fig 3.).
Observing the problem, it can be concluded that precision depends on three characteristics:

- Coincidence of table center and its rotation axis
- Equality of seats to table center distances
- Equality of angles between individual seat and corresponding slot

These characteristics can be seen on geometric problem presentation on Fig. 2.
Parameter definition:

- O – table rotation axis
- Op – table center
- A – clamper position
- B_1 – position of prime seat – tool
- B_i – position of further seat
- OOp – table center to table rotation distance
- OpB – individual seat to table center distance
- γ_i – angle between individual seat and corresponding slot
- Z_i – position error
- α_i – angle between consecutive slots
- φ_i – angle of distance OOp

Following relations can be drawn from Fig.2.

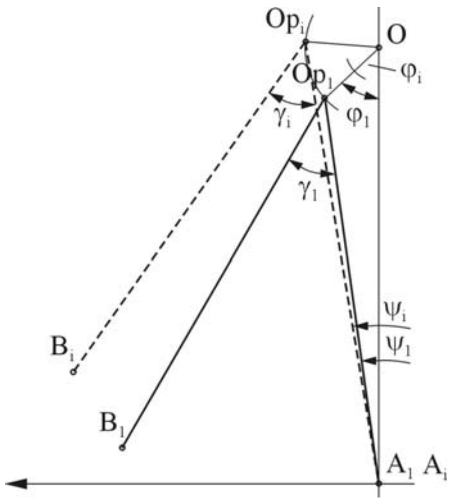

Figure 2. Precision definition

$$\sin\psi_i = \psi_i = \sin\varphi_i \cdot \frac{\overline{OOp_i}}{\overline{Op_iA}}$$

$$\overline{Op_iA} = \sqrt{\overline{OA}^2 + \overline{OOp_i}^2 - 2\cdot\overline{OA}\cdot\overline{OOp_i}\cdot\cos\varphi_i} \qquad \varphi_i = \varphi_{i-1} + \alpha_i \tag{1}$$

$$xOp_i = \overline{OOp}\cdot\sin\varphi_i \qquad yOp_i = \overline{OA} - \overline{OOp}\cdot\cos\varphi_i \tag{2}$$

$$xB_i = xOp_i + \overline{Op_iB_i}\cdot\sin(\gamma_i - \psi_i) \qquad yB_i = yOp_i - \overline{Op_iB_i}\cdot\cos(\gamma_i - \psi_i) \tag{3}$$

$$Z_i = \sqrt{(xB_i - xB_1)^2 + (yB_i - yB_1)^2} \tag{4}$$

The simplification is included in this presentation that says that the distance between a clamper and table center is not changing, that is not exactly correct.

2. PRECISION ANALYSIS

In precision analysis, only the worst case scenario will be examined, and not the statistical variation calculation. The base for analysis is existing working drawing partially presented in Fig. 3.
Regarding first two characteristics mentioned in chapter 1.2 it can be concluded that better precision can be achieved only by narrowing dimension tolerances and adopting such a manufacturing technology that will minimize the error. In 'equality of seats to table center distances' only one dimension tolerance is in question, but in 'coincidence of table center and its rotation axis' we deal with numerous dimensions inside the table carrier assembly that define the position of the table according to frame. This assembly is not an issue in this paper, and therefore concentricity of table carrier and the frame will be observed as given value.

In the third characteristic – ‘equality of angles between individual seat and corresponding slot’, the dimensioning manner has a great significance. These angles – γ_i can be calculated using angles between consecutive seats (β_i), consecutive slots (α_i) and angle δ (see Fig. 3) in a following way:

$$\gamma_1 = \delta + \alpha_1 \tag{5}$$

having in mind position of the first seat and the clamper. For further seats

$$\gamma_2 = \delta + \alpha_1 + \alpha_2 - \beta_1$$

$$\gamma_3 = \delta + \alpha_1 + \alpha_2 + \alpha_3 - \beta_1 - \beta_2 \qquad \text{or}$$

$$\gamma_i = \delta + \sum_{j=1}^{i} \alpha_j - \sum_{k=1}^{i-1} \beta_k \quad i = 2.....16 \tag{6}$$

In the case presented on Fig. 3, chain dimensioning is adopted for angles α_i and β_i. That means that angle tolerance will accumulate and, for later seats the error can be significant:

$$Z\gamma_i = \gamma_i - \gamma_1 = (i-1)\cdot \alpha_{max} - (i-1)\cdot \beta_{min} = (i-1)\cdot Za \tag{7}$$

where

- $Z\gamma_i$ – tolerance (error) of particular angle γ
- Za – defined angle tolerance (for simplification, all angles were defined at the same way)

The better solution is adoption of datum dimensioning of all seats and slots, beginning with prime seat and prime slot. In this case, we have:

$$Z\left(\sum_{j=1}^{i} \alpha_j\right) = Z\left(\sum_{k=1}^{i-1} \beta_k\right) = Za \qquad \text{and} \tag{8}$$

$$Z\gamma_i = \gamma_i - \gamma_1 = \left.\sum_{j=1}^{i} \alpha_j\right|_{max} - \left.\sum_{k=1}^{i-1} \beta_k\right|_{min} - \alpha_{1min} = 1.5\cdot Za \tag{9}$$

Direct dimensioning of angle between corresponding seat and slot (γ_i) would minimize an error:

$$Z\gamma_i = \gamma_i - \gamma_1 = Za \tag{10}$$

The problem of tolerance of angle γ_i would be completely avoided if corresponding seat and slot would be manufactured simultaneously. In that case manufacturing process would simulate working one, and perfect precision for every position of the table would be achieved regardless of angle tolerance. Position of the slot that enables easiest way of simultaneous manufacturing should be analyzed.

Unfortunately, this approach actually does not give satisfactory solution in this machine. There are four tools, and even if the seat perfectly matches the first one, it also reaches the position beneath other three, where an error is imminent. That analysis leads to simultaneous manufacturing of 8 elements: 4 seats (at 90°) and 4 corresponding slots. This complicates the manufacturing, while tough precision requirements for those elements still remain.

If simultaneous manufacturing is avoided, errors for other tools can be found in the similar way as to the first one (Eq. 5, 6). For the second tool there are:

$$\gamma_1 = -\delta - \alpha_1 + \sum_{k=1}^{4} \beta_k \tag{11}$$

$$\gamma_i = -\delta - \sum_{j=1}^{i} \alpha_j + \sum_{k=1}^{i+3} \beta_k \quad i = 2.....16 \quad \text{za} \;\; k \geq 17, \;\; k = k - 16 \tag{12}$$

For the third and fourth tool, equations 11 and 12 are the same, only the range of k is changing to 8 and 12 in Eq. 11 and to i+7 and i+11 in Eq. 12 respectively.

The position tolerance for other tools will be the same as for the first, given in Eq, 9.

3. CALCULATION RESULTS

Some of results of maximum error calculation for the mentioned design (Fig. 3) are presented.
Maximum value of OOp is 0.02 mm, consisting of concentricity error of table carrier and the frame and concentricity error of seat center circle according to table seating circle (Fig. 3).
Allowance of OpB is ± 0.006 mm, since seat center circle radius is 400 ± 0.012 mm.
All angles α and β are defined as 22,5±0.003°. Arbitrary angles φ are inspected. Equations from chapter 1.2 are used. Table shows results for second, seventh and twelfth seat (i = 2, 7, 12), according to first and second tool, for angles φ of 150 and 270 degrees.
Angle α_1 is set to 22.497 °, and for the second tool $\Sigma\beta_{1-4}$ = 90.003 °.

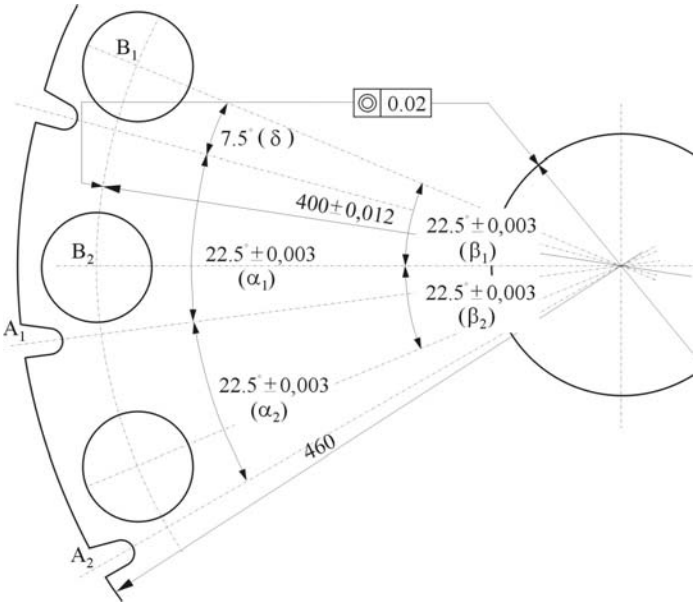

Figure 3. Working drawing of the table

	$\Sigma\alpha_j$ (deg)	$\Sigma\beta_k$ (deg)	φ (deg)	Z (mm)
I tool	45.003	44.997	150	0.023
	45.003	44.997	270	0.026
	157.503	157.497	150	0.019
	157.503	157.497	270	0.044
	270.003	269.997	150	0.042
	270.003	269.997	270	0.032
II tool	45.003	112.497	150	0.046
	45.003	112.497	270	0.050
	157.503	224.997	150	0.087
	157.503	224.997	270	0.043
	270.003	337.497	150	0.075
	270.003	337.497	270	0.026

Table 1 Calculation results

4. CONCLUSION

Observing the problem of rotary table precision, it can be concluded that precision depends on three characteristics: coincidence of table center and its rotation axis, equality of seats to table center distances and equality of angles between individual seat and corresponding slot.
Regarding first two characteristics, it can be concluded that better precision can be achieved only by narrowing dimension tolerances. Calculation shows that their influence on precision is marginal. Much more significant is the equality of angles. Beside defined tolerances, dimensioning manner and manufacturing technology has great impact. The highest precision can be achieved by simultaneous manufacturing of seat and corresponding slot, i.e. when manufacturing process is simulating the working one. However, because of multiply tools, that is not enough, and strict tolerances of particular seats must be maintained. By all means, it is not satisfactory to adopt chain dimensioning, that is common for similar designs.
A specific precision problem occurs when two clamping devices are adopted. It can be assumed that their position according to the table will not be precise which inevitably leads to table positioning error. That issue should be thoroughly examined.
It can be concluded that a serious error in particular seat to tool position can not be avoided. The designer must have in mind that fact and, in tool design, he must find the safest way in which the tool will enter the seat.