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A Review on Design of Compaction Press Tool

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Abstract

The real advantage of PM is to cost effectively produce large volume, highly tolerance metal components & widely applied to produce mainly automotive parts such as bearings cap, cams, synchronisation hub, sprocket and toothed components. The ongoing debate has always centred on properties, such as strength, size and life of Tool. Tool material selection and material characteristics are being engineered to specific applications and requirements. Flexibility and knowledge of process variables is the key for both the end-user and the component manufacturer. We, as an industry, see challenging new horizons that only require a little inspiration, ingenuity and persistence. There is little repetitive failure during production of Compaction (Forming) press tool found in manufacturing process. Each failure causes very high Economical cost to manufacturer in terms of production loss due to down time as well as commitments to the customer. The failure analysis of this compaction press tool was found most interesting. During these work modes of failures of tool was studied to conclude and recommend the solution. Design of compaction press tool was the methodology used to analysis the problem. Reviewed the history of the compaction tool compared the capacity of the pressing various possible design conditions, results and conclusion of the study will be very useful for compaction in future planning process.

Keywords: Compaction Press Tool.

Introduction

A metal powder compaction tooling set consists of a die, Top punches, Bottom punches and a set of springs. The distribution of radial stress, tangential stress of die and buckling analysis of punches has been analysed using Finite Element Analysis. Further, the compaction tooling set was fabricated as per the design analysis. All compacting tools work by the same general principle: Metal powder is filled, by gravity, into the cavity of a rigid die. There it is being compacted between two or more axially moving upper and lower punches to form a body of more or less complicated shape and of fairly homogeneous density. The compacting cycle can be divided into three stages:

1) Filling the die,   2) Densifying the powder, and 3) Removing the compact from the die.

Each of these stages is characterized by specific positions or movements of the individual tool members. And in each of these stages, specific technical problems occur.
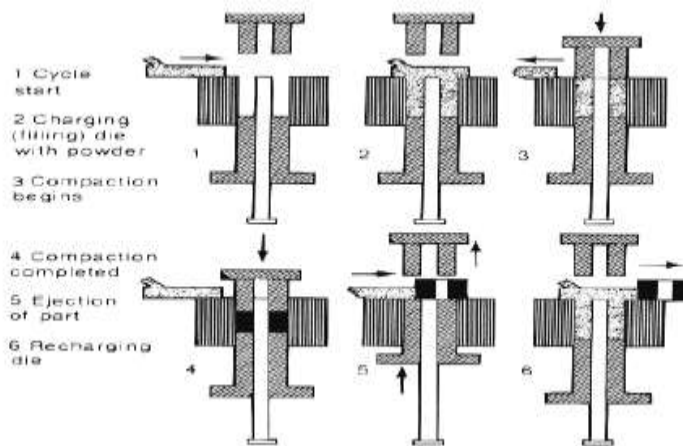
Figure 1.1: Compacting Cycle

Failure Analysis of Tool

There are different failure reasons of tool, but major failure are as given below,

1. Wrong Mechanical adapting assembly of tool and die.
2. Improper tool material selection.
3. After excess uses tool wear and tear.
4. Poor design consideration or factor of safety like Fatigue, Compressive & Buckling load.
5. Achieving high density of compacted parts.
6. Manual tool handling during assembly and tool room (Human error).
7. Improper heat treatment during tool manufacturing process.

Designing a Compacting Tool

In the following, we outline the principle procedure of designing a compacting tool. As a Representative example, we choose a part having two parallel holes and two portions of different height as shown in fig.3.1. Based on the technical drawing of this structural part, a proportionally correct sketch of the tool is being developed from which the required functions of the various tool members can be understood. Subsequently, exact dimensions and tolerances for all tool members are being established. Eventually, adequate tool materials as well as machining- and heat-treating procedures are being considered.
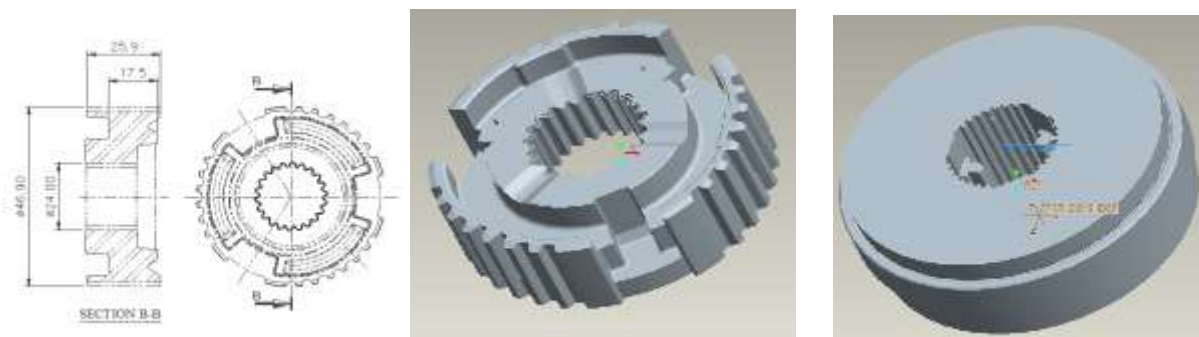

Figure 3.1: Sketch & 3D Model of compacting tool

Functional Sketch of the Tool

The development of the functional sketch proceeds, essentially, in four steps:

Step 1:
First, it has to be decided which way around the part is best to be compacted. Since the part has one relatively Teeth and one stepped face, the most practicable way to compact it is required one Top Outer Punch, second is Top Inner Punch-1 for preparation of counter

diameter and last one is for boss diameter is Top Inner Punch-2 . Then, two lower punches required, one is for teeth face and another one is boss and counter face

Step 2:
After it has been decided with which side up the part is to be compacted, a vertical section through the part is outlined on drawing paper and all vertical boundaries of the section are extended upwards and downwards. These extended lines indicate already the

vertical contours of die, punches and core rods. The horizontal boundaries of the section indicate the positions of the punch faces at the end of the compacting stage.

Step 3:

The required filling depths for the two portions of the part can be calculated by means of the ratio Q between compact density and filling density (apparent density) of the powder according to the following relationship:

Q = Compact Density/Filling Density
= Depth of Fill/Height of Compact

Commercial iron powders have filling densities between 2.4 and 3.0 g/cm³. If we base our example on an assumed filling density of 2.60 g/cm³, and an assumed compact density of 6.45 g/cm³, then:

Q = 6.45/2.60 = 2.47

In order to obtain the required depths of fill, the heights H1 and H2 of the two portions of our part have to be multiplied with this factor. The height of the left portion of the part is H1 = 25.9 mm, and the height of its right portion is H2 = 17.5 mm.

Thus, the respective depths of fill are,

F1 = 25.9*2.47 = 63.973 mm and F2 = 17.5*2.47
= 43.225 mm.

We decide that the left powder column is to be compacted symmetrically from top and bottom. This means, during densification of the left powder column, the upper punch and the left lower punch are to travel equal distances inside the die. Consequently, at the end of the densification process, the centre of the left portion is located half-way between the upper rim of the die and the filling position of the left lower punch. Thus, we mark the position of the upper rim of the die at distance F1/2 = 31.987 mm above and the filling position of the left lower punch at distance F1/2 = 31.987 mm below the centre of the left portion. Then, at distance F2 = 43.225 mm below the so found upper rim of the die, we mark the position of the right lower punch.

Step 4:

Assuming that a minimum guidance in the die of 25 mm is required for the lower punches, the die has to be at least 25 mm higher than the largest filling depth. Thus, we mark the lower rim of the die at distance A = F1 + 25 mm = 88.973 mm below its upper rim. Eventually, the lengths of the punches are to be considered. Both lower punches have, of course, to be long enough to fully eject the compact from the die, i.e. they have to be at least 88.973 mm long. The upper punch has, of course to be long enough to penetrate the die as deep as needed to attain the desired compact height, i.e. its length has to be at least (F1 - H1)/2 = 19.04 mm. To these lengths, a margin of 5 - 10 mm should be added to allow for the correction of worn

punch profiles. After this, the rough design of our compacting tool is complete.

Dimension & Tolerance on Tool Members

When pinpointing the final dimensions and tolerances for the various tool members, not only the final dimensions and tolerances of the structural part, as specified on the customers' drawing, must be considered, but also the dimensional changes which the compact undergoes during ejection from the compacting die and during subsequent sintering. Dimensional changes of the compact's longitudinal dimensions do not constitute any greater problem, because they can relatively easily be compensated for by slight adjustments of punch positions and movements. Much more critical are dimensional changes of the compact's transversal dimensions, because they cannot be adjusted without disassembling the compacting tool and regrind or entirely remake die and punches. Thus, before finally laying down transversal dimensions and tolerances of tool members, it is most important to very carefully establish the dimensional changes of the compact under production-like compacting and sintering conditions. Dimensional change data from previously produced parts of similar shape and composition may be a good guidance. To rely solely on data established under laboratory conditions is risky. In this context, it must be kept in mind that dimensional changes during sintering are sensitive not only to variations in sintering temperature and time but also to variations in powder composition and compact density. We demonstrate the procedure of calculating the transversal dimensions of a compacting tool for the case of a Straight bushing. The drawing of the bushing specifies:

Outer diameter = Da, Tolerance = +ΔDa, Inner diameter = Di, Tolerance = -ΔDi

From previous production of similar bushings, the following data are known:

Average spring-back after compacting = e %,

Average dimensional change during sintering = s % (+ for swelling, - for shrinkage).

The tool dimensions to be calculated are: inner diameter of the die = dm,

And outer diameter of the core rod = dk.

It is to be expected that, due to wear during production, the inner diameter of the die (dm) increases and the outer diameter of the core rod (dk) decreases. In order to keep the dimensions of the sintered bushing within specified tolerances, the following limitations have to be observed when dimensioning die and core rod:

(Da + ΔDa)/(1+e+s) > dm > Da /(1+e+s) ..... (5.1)

Di/(1+e+s) > dk > (Di - ΔDi)/(1+e+s) …. (5.2)

Theoretically, the optimal utilization of die and core rod would be attainable if the initial value of dm is as small as the right side of (5.1) allows, and the initial value of dk as large as the left side of (5.2) allows. In order to make sure that the dimensions of the sintered bushings are within specified tolerances even in case dimensional changes e and s should vary, the specified tolerance ranges are narrowed at both ends by 20 %. In other words, it is being assumed that the specified limits are Da+0.2ΔDa and Da+0.8ΔDa for the outer and Di - 0.2ΔDi and Di - 0.8ΔDi for the inner diameter of the bushing. Thus, for the inner diameter of the die and for the outer diameter of the core rod, the following relationships are stated:

dm = (Da + 0.2ΔDa)/(1 + e+ s) …... (5.3)
dk = (Di – 0.2ΔDi)/(1 + e + s) ……(5.4)

Consequently, the allowable wear on the die is:

Δdm = 0.6ΔDa/(1 + e + s) ………..(5.5)

and the allowable wear on the core rod is:

Δdk = - 0.6ΔDi/(1 + e +s) ……...(5.6)

Applying equations (5.3) to (5.6) to the structural part, we can now calculate the final transverse dimensions of the compacting tool. According to specifications on the drawing, the outer diameter of the higher portion of the part is Da = 46.90 mm with tolerance ΔDa = +0.20 mm, and its inner diameter is Di = 24.00 mm with tolerance ΔDi = -0.018 mm. We assume that the average spring back is e = +0.1% and the average dimensional change during sintering is s = +0.4%. On the basis of these data, we obtain for the initial values of the inner diameter dm of the die and of the outer diameter of the core rod dk:

dm = (46.90 + 0.2/5)/1.005 = 46.821 mm
dk = (24 – 0.018/5)/1.005 = 23.937 mm

and for the allowable wear:

Δdm = (0.6/5)/1.005 = 0.119 mm
Δdk = -(0.054/5)/1.005 = -0.011 mm

As an example, a circular die cavity can be ground and lapped to a tolerance 0.005 mm and a circular punch can be made to a similar tolerance, thus giving a total tolerance for the two parts of 0.010 mm. If we require a clearance between die and punch of 0,010 to 0.015 mm, it is clear that it is better to state a tolerance only for the die which actually forms the profile of the compact, and give the punch size as a clearance rather than as a size with a tolerance. This method gives the toolmaker a better opportunity to produce an effective clearance without working to impossible tolerances.

Generally accepted clearances are given in Table 5.1 When applying the approximate clearances recommended in table 5.1, it must be kept in mind that punches expand elastically under the compacting load. This means that the clearance between die and punches decreases and the clearance between core rod and punch increases. The application of such narrow clearances to profiled dies and punches presents a difficult tool making problem, but the satisfactory running of the tool over a reasonable period does not permit greater clearances. A prerequisite for a long tool-life is an extremely good finish on all sliding surfaces (typical: 0.2 μm) and a proper pairing of the surface hardness's of the sliding partners. Here applies an old rule from mechanical engineering: Sliding partners should not be made from exactly the same material and must have different surface hardness's.

Table 5.1 Recommended clearances between sliding tool members:

Tool Dimension (mm)	Clearance (≈ IT 5) (μm)
≤ 10	10 – 15
10 – 18	12 – 18
18-30	15-22
30 – 50	18 – 27
50 – 80	21 – 32
80 – 120	25 – 38

Tool Material
Punches:

As has been mentioned before, powders are usually compacted with pressures between approx. 300 and 650 N/mm2. All punches of the compacting tool have to withstand theses high loads not only once but several 1,00,000 to 10,00,000 times without breaking or getting plastically deformed. Neither may they under these loads expand elastically to such an extent that they jam in the die. Even an ever so small amount of plastic deformation during one compacting cycle would, after a number of cycles, lead to a sizable shortening and thickening of the punch. It does not take much imagination to realize the consequences: As the punch gets shorter, the height of the compacts increases correspondingly, and as the punch gets thicker, it eventually jams in the die and breaks and possibly damages the entire tool. Thus, punches must possess high compressive yield strength, high toughness and high fatigue strength. In cases where punches form part of the side walls of the compacting tool, they must, in addition to the mentioned properties, have a sufficiently high surface hardness. Surface-hardening of punches, if necessary, has to be carried out with great care, in order to avoid embrittlement and surface cracking. Only the toughest types of tool steels are suitable for punches. Ideally, they should combine the following properties:

1. Good machinability when soft-annealed.
2. Highest possible toughness and fatigue strength after hardening.
3. Highest possible dimensional stability and lowest possible susceptibility to cracking in the hardening procedure.
4. Highest possible wear resistance.

Selecting the right tool steel for a particular punch, and choosing the appropriate heat treatment, is mainly a matter of experience. Specification charts and heat-treating suggestions provided by steel makers can be helpful. Properties and heat-treating suggestions for three typical tool steels suitable for punches are presented in Table 6.1.

Dies and Core Rods:
Dies and core rods should best be made from cemented carbides. Although being much more expensive than steel, cemented carbides, because of their extremely high hardness and superior wear resistance is the most economic choice for large production series. For shorter series, however, certain high-speed steels are a less expensive alternative. Due to their high content of hard carbides embedded in a tough steel matrix, high-speed.

Table 6.1 Properties of Tool Steels suitable for Punches:

Swedish Steel Standard	SIS 2140	-	– SISI 2550
German Steel Standard	**~ 105WCr6**	**90MnV8**	**50NiCr13**
ANALYSIS: % C	0.95	0.85	0.55
Si	-	-	-
Mn	1.2	2.1	-
Cr	0.5	-	1.0
Ni	-	-	3.0
Mo	-	-	0.35
W	0.5	-	-
V	0.1	0.12	-
Normalizing temperature °C	800 – 820	800-820	790-810
Annealing Temperature °C	750 – 770	690 – 710	740 – 760
Hardness after annealing HB	190 – 210	180 – 200	220 – 250
Machinability	Good	Good +	Fair
HARDENING: Resistance to decarburization	Fair	Fair	Good
Austenitizing temperature °C	790 – 810	770 – 810	790 – 810
Quenching medium	oil or salt bath	oil or salt bath	oil or salt bath
Tempering temperature °C	250 – 260	230 – 240	260 – 270
Hardness after tempering HRC	62 – 50	63 – 50	58 – 50
Dimensional stability	Good+	Good+	Good+
Distortion or warping stability	Good+	Medium when oil quenching.	Good when oil quenching,
Wear resistance	Fair+	Fair	Fair
Toughness	Good	Good+	Best when 2x tempering.

Consideration for the designing tool
The following twelve points may give a first clue to the problems involved in designing a powder compacting tool:

1. All portions of the die cavity must, in a reliable way, be filled with exact amounts of powder.
2. The density distribution in the compact should be as homogeneous as possible.

3. In all portions of the die cavity, the densification of the powder should take place simultaneously, in order to warrant a sufficiently good binding between adjacent portions. It has to be taken into account that powder flows only very little in lateral directions during densification.

4. The compact must be removable from the compacting tool without getting damaged.

5. All required movements of tool members must be adequately controlled and must be repeatable with sufficient accuracy.

6. The tool should have as few punches as possible.

7. During the entire compacting cycle, punches must never jam, neither with the die, nor with core rods, nor with one another.

8. All tool members must withstand the load exerted upon them during the compacting cycle. They must be as wear-resistant as possible and have the highest possible life expectancy.

9. All functions of the tool must be optimally adapted to the functions available on the compacting press.

10. In order to keep set-up times to a minimum, the design of the tool should be such as to facilitate assembling and installation on the press.

11. In order to keep production stops as short as possible, worn-out tool members should be as easily replaceable as possible

12. The manufacturing costs for the tool must be reasonable in relation to its expected life-time and to the total number of compacts to be produced.

Conclusion

Parameters are distributed for the designing the tool is scale factor and offset factor.

1. Sintering, Spring Back, and Heat Treatment are parameters considered for scale factor.

2. Coating, Tool Clearance, Insert Clearance, Tool wear are parameters considered for offset factor.

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