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Design of Special Purpose Machine for Counter boring Operation on the hub of an impeller blade

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Abstract
Special Purpose Machines are designed to carry out certain kind of specific operation in a high volume production. It was necessary for us to carry out four counterboring operations on the hub of the blade as shown in figure 1 and the blade profile has interference with one of the four holes for fastening and therefore cannot be machined for large production using conventional machines. And thus it is planned to design a special counterboring machine for this typical operation.
A new design was proposed by overcoming the limitations of the conventional counterboring operations. An optimized design was presented to carry out multiple (four) counterboring operations in a shorter time period. This paper also explains the design of the gear drives and shafts of the Special Purpose Machine.

Keywords: Special Purpose Machines, counterboring, axial profile fan blade, Impeller blade design and manufacturing, counterboring of interfering profiles

Introduction
Special purpose machine and tools are designed and manufactured for specific jobs which can be beneficial in increasing production and reducing manpower. The techniques for designing such machine would obviously be quite different from those used for mass produced machine.
M. Tolouei-Rad [1] investigated the possibility of application of knowledge-based expert systems to facilitate the task of techno-economical feasibility analysis of utilization of special purpose machines for high quantity production tasks. Furthermore H.S. Rahate et al.[2] idealized a simplified operation of spot facing in industrial valves. H.S. Rahate suggested that the dedicated special purpose machine for back spot facing operation for a industrial valve. The efforts are done to reduce the operation time, reduce the cost of product and for increasing the productivity of the machine. It can able to perform back spot facing operation simultaneously on complete flange. In the same way it can reduce the human fatigue and minimize the problem of availability of skill labor. P.R. Sawant, et al. [3] has made a case study and comparison of productivity of component using conventional radial drilling machine and special purpose machine (SPM) for drilling and tapping operation. From the above studies, it reveals that the Special Purpose Machine (SPM) not only reduces the time for the operation but also makes more profit for the company by limiting the human effort and increases the high quantity production tasks along with the reduction in the operation time. Considering the above literature, it was decided to design a Special Purpose Machine for the counter boring operation.

Counterboring and component description
Counterboring is an operation of enlarging the end of a hole cylindrically. The counterbores are made with straight or tapered shank to fit in the spindle. The cutting edges may have straight or spiral teeth. The tool is guided by the pilot, which extends beyond the end of cutting edges. The pilot fits into the small diameter hole having running clearance and maintains the alignment of the tool.
Figure 1 shows the top view of the blade profile in which the hub of the blade profile has to be counterbored in four locations namely A, B, C and D and figure 2 shows the counterbore screw which has to be fitted in to the holes A, B, C and D. The counterboring tools which can be used for machining the hole is shown in figure 3. In order to connect the blade to the impeller, the counterbore has to be done on the hub of the blade shown in figure 1. The holes A, B and C can be machined using conventional machine, whereas the hole D has interference with the blade profile as shown in figure 1 (red line shows the blade profile fall in interference with the hole), therefore cannot be directly machined using conventional machine.

The need for SPM
Conventional counterboring method cannot be used due to space restrictions and interference of the blade profile.
For a single production it is advisable to use conventional machine with a fixture that can facilitate the process but for batch or mass production a Special Purpose Machine is required for carrying out such operations. This special purpose machine was designed to carry out a counterboring operation for the given blade profile. The challenges faced while designing a Special Purpose Machine are listed below,

i. The Counterboring operation has to be made to fit the fastener shown in figure 2.
ii. Tool approach is constrained due to less space.
iii. Counterbore is to be done on the top side of the blade hub.
iv. Blade Profile overlaps the Counterbore (1 hole).

v. Productivity/Speed/Quality.

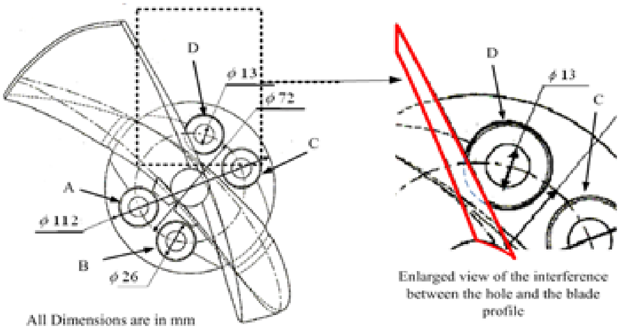


Figure 1: Top view of the blade profile

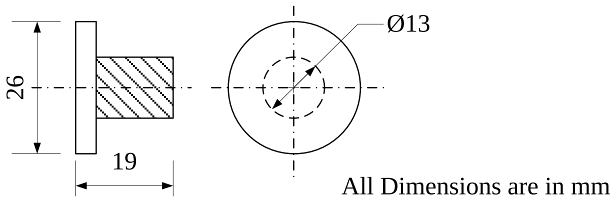


Figure 2: Screw Fastener which connects the blade hub to the impeller

There is no readymade solution available for making counterboring operation for a typical section (explained above in section 1) using conventional methods and thus a new design is required to overcome the limitations of the conventional type counterboring operations. The main limitation of the conventional counterboring operations lies with the unavailability of standard equipment that facilities, large scale production considering the difficulty in the process. Groover [4] has shown the existing counterboring techniques and is shown below in figure 3.

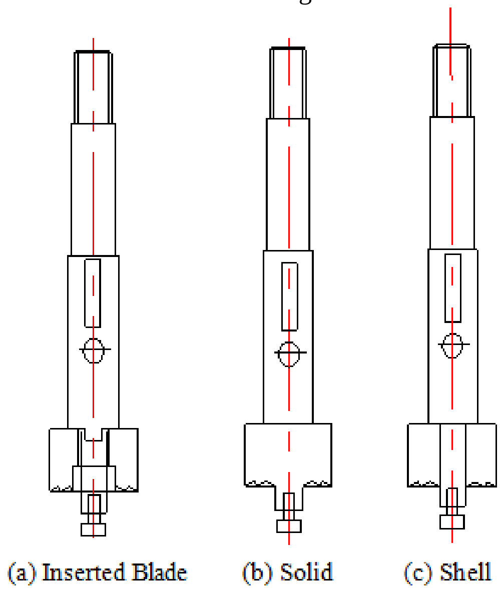


Figure 3: counterboring tools

a) Counterboring Tool with suitable holder

Using Counterboring Tool with suitable holder is not possible because the Blade Profile overlaps the Counterbore.

b) Counterboring with Spot facing tool

Using Spot facing Tool for counterboring Operation is slender and difficult to Counterbore the required 13mm also the fillet portion of the Blade results in uneven machining so the spot facing mandrel will fail.

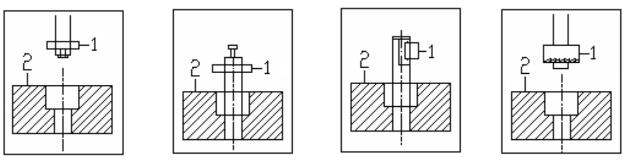
c) Counterboring with Pivot type Fly cutters

Using pivot type fly cutters the load due to the Counterbore side that is 13mm-26mm is more and tool fail. So it is warranted to design new tool to give the required result like size speed and quality.

d) Counterboring by Back boring method

Back boring is a process of enlarging the hole from rear side of the work piece. This process can be applied where the tool’s approach is constrained due to less space. Since this process suits all the requirements, we chose the concept of Back Boring Method as the ideal solution for this problem
From the above (a)-(d), the techniques (a,b and c) do not suit the requirement for making counterboring operation on the impeller blade, whereas (d) Counterboring by Back boring method finds easier to make the counterboring operation.
The requirement for a new special purpose machine is not only to make counterboring operations of the typical section but also to aid the advantages of the following conditions,

i. Simple design in construction.
ii. Easy to implement.
iii. Cost effective.
iv. Should improve productivity.
v. Ensuring the availability of spares.
vi. Adaptability to similar components.
vii. Machine must be workable and reliable.
viii. To achieve maximum quality.



Note 1-Specifies the tool and 2-indicates the component/specimen

Figure 4: Conventional counterboring operations

Design of Special Purpose Machine for Counterboring operation

By considering all the above said problems in section 2, the requirements/concept of the new Special Purpose Machine is derived as follows:

i. Special Counterboring Cutter to suit the situation.
ii. Gears to transfer the power from the source to the cutter.
iii. Shafts to hold and transmit the power to gears and cutters.
iv. Frame to keep all the components of our machine in place.
v. Bearing bushings to suit the condition.
vi. Power source i.e. Electric Motor.
vii. Fixture to hold the component rigidly.
viii. Feed the component at required rate.

Apart from the above requirements, it is necessary to consider the Economic Feasibility, Reliability, Maintenance, Safety, Ease of Operation, Manufacture/Production, Material Cost, and Efficiency of the machines along with their Environmental constraints. The design process involves various steps and are explained below,

i. After a careful study of requirements sketches of different possible mechanism of the Machine.
ii. Next step in design procedure is to prepare a Block Diagram showing general layout of the selected configuration as shown in figure 5 (displayed at the end of the paper)
iii. Verification of the model
iv. The Design of individual components is the next important step in the Design Procedure.
v. The later step involves the 3-D model of each component and the final assembly of the Special Purpose Machine using modeling software.
vi. Final stages of the design involve the production of designed component.

A. *Counterboring operation using Special Purpose Machine (SPM)*

The following explains the proposed new model for counterboring operation. Figure 5 and Figure 6 shows the schematic and 3-Dimensional view of the Special Purpose Machine and table 1 shows the Bill of materials along with working flow chart.

The primary source of the power to the belt drive is provided by means of a motor. The spur gears are used for transmitting power between parallel shafts. The belt drive transmits the rotational torque to the Gear 4 (refer bill of materials and figure 5) via shaft 3 which further transmits the power to the four of the gears i.e., Gear 3 (4 Nos.) by means shaft 2 (4 Nos.). The Shaft 2 further transfers the rotational motion via a gear-pinion drive to the Shaft 1.

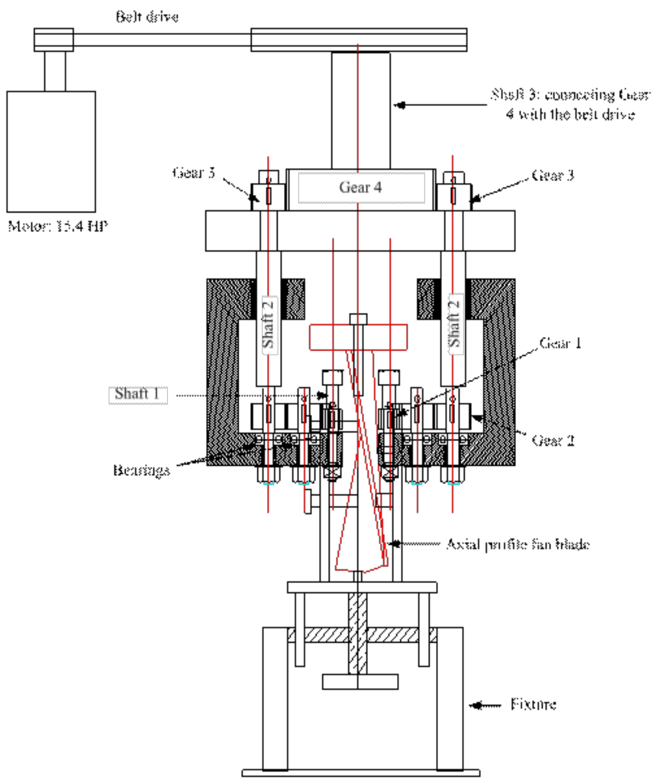


Figure 5. Schematic view of special purpose machine

B. *Design of Special Purpose Machine components*

The components/drives used in the Special Purpose Machines are designed for its safety and service. It is a must to select the proper materials for the specified component so as to withstand the temperature, stresses which are generated during the process. Here the following discusses the design of Motor, Gears and Shafts, which are the most necessary transmission elements involved in the Special Purpose Machine.

Before proceeding to the design, it is necessary to note the desired parameters which are shown in Table 1.

TABLE.1. Design Parameters of Special Purpose Machine

Material to be bored:	Aluminium alloy.
Depth of cut	0.019 mm (with HSS tool).
Feed (f)	0.00025 m/revolution.
Cutting speed (S)	32 m / minute.
Diameter of the bore (D)	0.026 m.

Motor Design

The power required for making a counterboring operation for the specified parameters (refer table 1) is found using the equation 1,

Motor power, $P = 2\pi NT / 60 * 1000$ (1)

in which N is the Spindle speed (can be found using equation 2), T is Torque transmitted which is found using equation 3.

Spindle speed, $N = S / \pi D$ (2)

in which S, the cutting speed can be obtained from the table 1. The torque required for the motor drive can be found from the equation 3,

Torque, $T = C * f^{0.75} * D^{1.8}$ (3)

in which C is the constant [5], f is the Feed in m/revolution and D is the diameter of the bore.

From equations 1, 2 and 3, the motor power required is found to be 3.83 HP for making single hole. And thus for making counterboring for four holes, the total moter power required is found to be 15.35 HP (Horse power).

Gear Design

There are two gear drives incorporated with the assembly for transmitting the power from the belt to the tool assembly. Since the gears have to withstand the vibrations created by the cutting force the material selection is an important factor. The material used is case hardened alloy steel which is used for heavy duty continuous running machines which can withstand the vibrations generated during the cutting operation with good load carrying capacity.

The material used for the gears and pinion are Alloy steel 40 Ni2 Cr1 Mo28 case hardened to 63 RC, core hardness < 350 BHN. The assumed life of the gear drive is found to be 26 * 107 cycles and the equivalent young's modulus [5] found to be 2.1 * 105 N / mm2.The details of the gear such as dimensions and other related parameters are found using the Machine Tool handbook [5].

Deign bending stress, $[\sigma_b] = (1.4\, k_{bl}\, \sigma_{-1}) / (n \times k_\sigma)$ (4)

Deign contact stress, $[\sigma_c] = C_R \times HRC \times k_{cl}$ (5)

Design Torque, $[M_t] = [P \times 60 / 2\pi \times N_1]$ (6)

Induced bending stress (Pinion),

$\sigma_{b(p)} = (i+1)M_t / a \times m \times b \times y$ (7)

Induced bending stress (gear), $\sigma_{b(g)} = (\sigma_{b(p)} * y_p) / y_g$ (8)

Induced contact stress for pinion and gear are same and is given by equation,

$\sigma_c = 0.74 * \{i+1\}/a \sqrt{(\{i + 1\}/i*b)} * E * [M_t]$ (9)

TABLE 2. Design and Induced Bending and Contact stresses in gears

Terms		Gear drive I		Gear drive II	
		Design	Induced	Design	Induced
Bending Stress (N/mm^2)	Pinion	386.5	213.75	386.5	213.5
	Gear	386.5	316.3	386.5	175
Contact Stress (N/mm^2)		1764	1640.1	1764	1219
Torque (Nmm)		69720	64423	501550	328332

From Table 2, it can be said that the induced stresses developed in the gears are smaller than the design values and thus design satisfies the safety requirements for production.

Shaft Design

The total dimensions of the shaft were decided based on the gear design made in the previous section.

TABLE 3. Dimensions of the Shaft

Dimension	Shaft 1	Shaft 2	Shaft 3
Diameter (m)	0.02	0.025	0.045
Length (m)	0.07	0.25	0.11

C. Fixture and Feeding mechanism

The fixture is used to hold and support the blade for performing machining operations. The fixture is designed in such a way that it should not create any impression on the surface of the blade during holding. The fixture in this design is made of low carbon steel. The clamping of the blade to the fixture is provided by means of a screw clamp. The screw clamp provides the necessary force for clamping. Contact points are the points at which the clamping force is applied to the component. During clamping the blade surface will be subjected to a high clamping force which results in deformation in the profile of the blade along its surface. In the application of clamping even a small deformation is not allowed. This can be eliminated by the use of a separators or clamping pads. Aluminum pads are placed over the blade surface before clamping. Aluminum pads are preferred because the fan blade is made up of aluminum alloy, thus preventing the reactions at the contact points on the blade. Figure 6, shows the 3-Dimensional model of the Special Purpose Machine made for typical counterboring operation.

Conclusion

A special purpose machine has been designed to counterbore the hub of the impeller blade. This design can be used for performing reverse counterboring operation especially in conditions of restricted space. This design eliminates the difficulty in counter boring on the inner face due to hindrance and space limitation, caused by 26mm dimension. Gears are designed to achieve the required cutting speed and to take thrust load generated during operation. This new design reduces the operation time, which results in the increase of productivity.

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