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DESIGN AND FABRICATION OF CROSS CORRUGATED RECUPERATOR FINS FOR A MICRO GAS TURBINE

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ABSTRACT

The National Aerospace Laboratories, Bangalore is involved in the development of a 10kW micro gas turbine (MGT). A recuperator is mandatory for an MGT to boost the thermal efficiency of the unit. This paper describes in detail the fabrication process of efficient corrugated fins for deploying in the recuperator of an MGT. The use of corrugated fins in the recuperator of the MGT gives higher effectiveness compared to conventional flat fins. The paper, in detail, describes the various materials used and the heat treatment process used for manufacturing the forming and shearing die sets. All manufacturing accuracy requirements were achieved to get the required fin geometry. The formed corrugated fins were qualified through a series of tests and large number fins were formed for use in the annular recuperator of the Micro Gas Turbine.

1. NOMENCLATURE

L	Unfolded length of corrugated fin (mm)
$a_1, a_2, .a_n$	Length of the legs (mm)
$R_1, R_2, \ldots R_n$ (or) $r_1, r_2, \ldots\ldots r_n$	Bend radius (mm)
$q_1, q_2, \ldots.. q_n$	Spring-back factor
t	Fin thickness (mm)
$\alpha_1, \alpha_2, \ldots.. \alpha_n$	Bend angle at $r_1, r_2, \ldots\ldots r_n$
$\varnothing_1$	Fin profile angle (30^0)
$\varnothing_2$	Corrugation inclined Angle (45^0)

2. INTRODUCTION

A Micro Gas-turbine (MGT) is a power generating device. The advantages of the MGT over existing diesel engine generator sets are smaller size and weight, multi-fuel capability, lower emissions, lower noise, vibration free operation and maintenance.

A Micro Gas-turbine unit comprises of a compressor, combustor, turbine, an alternator, recuperator and a generator. In principle, compressed air is mixed with fuel and burned under constant pressure conditions. The resulting hot gas is allowed to expand through a turbine to perform work.

Recuperated units use a heat exchanger called a recuperator that recovers some of the heat from the turbine exhaust and transfers it to the incoming air stream from compressor before combustion. Hence, the amount of fuel required to raise the given turbine entry temperature is reduced. By using recuperators the micro gas turbine thermal efficiency can reach 25 to 30 percent. It has been investigated and proved in literature that an increase in

1% effectiveness will raise the efficiency of a gas turbine unit by about 0.35 % [1]. Therefore, a recuperator unit is mandatory for an MGT as it has considerable effect on the MGT thermal performance.

NAL has developed an annular recuperator with plate fins for a 10kW Micro Gas Turbine. An experimental study has been carried out to determine its performance. The effectiveness value of the recuperator achieved is small due to the low heat transfer area per unit volume. Hence, alternative fins designs have been considered to get an enhanced heat transfer surface area to improve the effectiveness value with minimum pressure loss on both the air and gas sides. The various corrugated surface fins were designed and manufactured by using special types of die sets. This paper describes in detail the corrugated fin design and manufacturing method. A universal die set was designed to get different corrugated fins. This paper also describes the various materials used and their heat treatment process used for preparing the die sets for forming and trimming the required corrugated fins.

3. PERFORMANCE FACTORS

The desired performance factors for MGT recuperators are summarized as follows [2, 3]

- High effectiveness (this means a counter flow arrangement) and low total pressure drop (< 5%) with the core pressure drop of about 3% and the remaining in the manifolds and piping.

- High operating temperatures and fluid pressures and steep temperature transients during startup and shutdowns

- Desired operation life without any maintenance especially for stationary power generation applications

- Good thermal shock, corrosion, oxidation and creep resistance and low thermal expansion.

- Compact and lightweight matrix with integral manifolds and mass producible at low cost

3.1. PERFORMANCE COMPARISON

The amount of heat transfer, effectiveness and pressure drop fully depends on the heat transfer area and its shape. The earlier manufactured plate fin heat transfer area was quite low when compared to the present corrugated fin. The performance estimate for the corrugated fin shows an increase in the effectiveness and reduction in the pressure drop. The flat fin recuperator effectiveness measured was around 45%; the reason behind the low effectiveness is the low heat transfer area per unit volume [4]. The estimated effectiveness of the corrugated fin is around 65%.

4. MODELING

The basic profile for the fin is generated using a standard sine function. The height and pitch (amplitude-H and wave length-P) of the sine curve plays a vital role in the fin design because changing this parameter will change the surface area and flow structure for heat transfer.

The optimum wave length/amplitude ratio is taken as 2. The basic geometry and co-ordinates of the corrugated fin is generated using a computer code. The co-ordinates thus generated are used in modeling software SOLIDWORKS for generation of corrugated fin plate. The 3D-model generated for a single corrugated fin geometry is shown in Figure-1a while the 3D-model for a double corrugated fin is shown in Figure-1b.

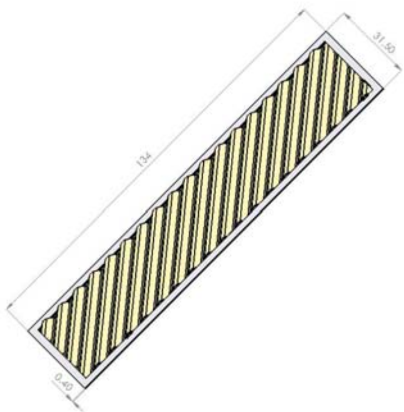


Figure-1a Single corrugated fin

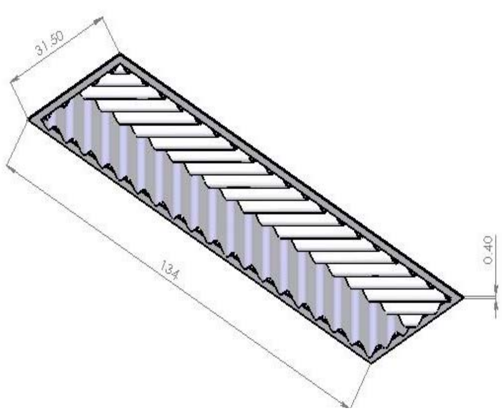


Figure-1b Double corrugated fin

5. MATERIAL SELECTION

Material selection is very important in the design as it is the critical factor in deciding the strength and durability of the component. It should be cost effective, which is the main factor to evaluate the overall cost of the product. Material chemical composition in percentage weight is another factor to decide the mechanical property as well as the physical property of the component.

5.1 FIN MATERIAL

AISI 304L annealed stainless steel sheet of 0.4mm thickness was used for the corrugated fins. This material has many advantages such as non-magnetic, high resistance to corrosion, soft, high stability and good mechanical property at elevated temperatures. Because of high nickel content in the material, it has an affinity to spring-back during forming. Hence it is essential to provide tool compensation in the forming process. This material also has very good weldability and coalescence property due to specific composition of Carbon (0.06%), Nickel (8.27%) and Chromium (18.27%) contents. Due to the percentage ratio of Nickel/Chromium the material plays a vital role in toughness and hardness. The procured raw material hardness was measured as 92 HRC. Hence the material needed to be softened for easy forming. This softening was done by rapid cooling to about 1010-1120 ºC followed by solution treatment.

5.2 DIE MATERIAL

The die sets consists of three major components namely die blocks, guide pins & locating pins and forming tools/shearing tools. The material used for die blocks and side support was EN24 an equivalent to SAE 4340. This material has a composition consisting of nickel (1.30%), chromium (0.90%) and molybdenum (0.20%). This material after a hardening process becomes resistant to elongation. The material used for the forming tool should have a lower hardness than the fin material. Hence, a high chromium and high carbon steel was selected. This material hardness was around 55-60HRC. The same material was used for blanking (shearing) operation. For shearing the material was hardened to 60HRC. The material used for guide, locating and load pin was Oil hardened non-shrinking Steel (OHNS) having high toughness and resistance to wear. High dimensional accuracy in machining can be achieved by using this material. The OHNS material has a composition consisting of carbon (0.9%), manganese (1.25%) and chromium (0.5%). Due to this typical combination in composition, the material possessed a hardness of 64 HRC. The die set consisted of 18 numbers of ground pins of 10mm diameter, which are used for guide and load support.

5.2.1 HEAT TREATMENT

The die blocks for forming and shearing tools were machined to the required size by conventional machining by keeping the required allowance for grinding. After the machining process, these are heat treated to get the required mechanical strength namely hardness and resistance to wear.

5.2.2 DIE BLOCKS AND FORM TOOS

In order to get the required hardness of the material EN24, die blocks were heat treated by hardening, quenching and tempering processes. The initial hardness from 17-19 HRC was increased to 44-50HRC. The EN24 die material was heated from normal room temperature to 860 ºC in a sealed quench furnace over a span of 1.5 hours and then maintained at the final temperature for one hour. Immediately after this the blocks were quenched in oil for a duration of 2.45 hours. After the hardening process, the blocks were checked for hardness and found to have 50HRC. This material was further tempered to reduce the hardness to 40-44HRC. For this, the material was kept in a separate furnace at a temperature of 200 ºC for one hour. This material was found suitable to withstand a gradual as well as impact loads.

The raw material used for the form tool had a hardness of 20-25 HRC. This material was also hardened to get an HRC of 60 in the same way as explained above. The process was carried out in a vacuum furnace and the heat treatment temperature was 1050 ºC for one hour. The material was then soaked for a duration of 2hours. Then it was quenched in oil followed by tempering at 180 ºC for two hours. After this process the material was found suitable to withstand any type of loads and could easily form the required fin and shear the SS 304L sheets.

6.0 MEASURE OF CORRUGATED FIN GEOMETRY

The corrugated fin size was 134mm in length x 31.50mm in width x 0.40mm in thickness; this gave an area of 4221 mm^2. The measured unfolded value was about 7229 mm^2 (183 x 39.50 x 0.40) which is nearly 1.71 times more than the plate fin geometry. Spring-back factor was calculated from the TABLE- I provided by data hand book [5] for a given ratio of fin radius to fin thickness. The parameters required to calculate the unfolded geometry is given in Figure-2. The unfolded length of the corrugated fin geometry was calculated from the equation given below.

$$L = \{a_1 + [r_2 + (q_1 \times t/2)]\, \pi\alpha_1/180\} + \{a_2 + [R_1 + (q_2 \times t/2)]\, \pi\alpha 1/180\} + \ldots + \{a_n + [r_n + (q_n \times t/2)]\, \pi\alpha_n/180\}$$

Table 1 Spring-back factor [5]

Ratio (r:t)	5.0	3.0	2.0	1.2	0.8	0.5
Spring-back factor (q)	1.0	0.9	0.8	0.7	0.6	0.5

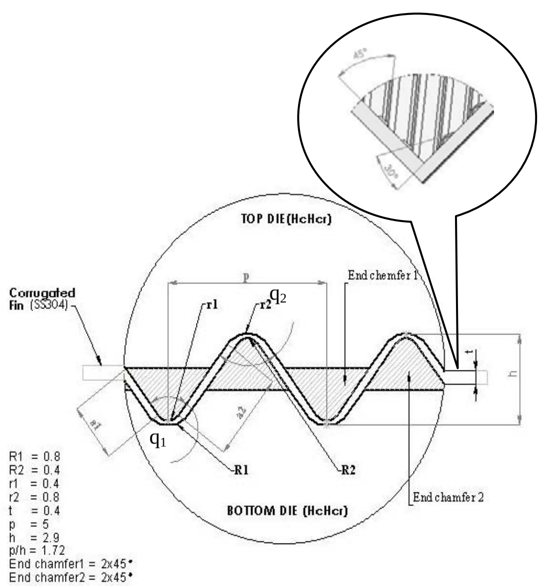


Fig. 2 Measure of corrugated fin geometry

6.1 SPRING-BACK EFFECT

There is always a tendency for certain amount of sheet metal spring back to the original state when the forming tools are removed in metal (SS304) forming. This can be reduced by a common method by giving extra features in radius, using smaller radius/chamfer or adding or modifying the draw beads to get an increased stretch of the blank. These techniques only reduce the effect of spring back but the formed part will always spring back a certain amount. The only way to get the formed part to be exactly as the desired shape is to have tool a geometry from the desired shape. The compensation or spring-back factor required is shown in Fig. 3. In the present forming die 0.1mm spring-back factor was provided on the bottom and top forming die sets in order to get required shape of the corrugated fin. The total spring-back factor provided on the forming die set will be 0.2 mm, which is the sum of factors provide on top and bottom surfaces, which is (B+C).

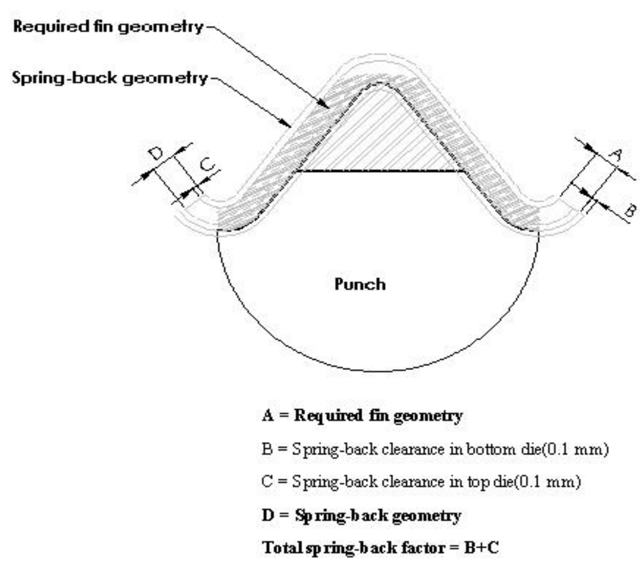


Fig. 3 Comparison of spring-backed shapes

7.0 MANUFACTURING PROCESS

The manufacturing process, as we call the sequence of machining operation, is directly concerned with changing the form of dimensions of the part being produced. The machining operations carried out to make multi combination die sets were three-dimensional manufacturing techniques like spark EDM, wire EDM with more traditional micromechanical manufacturing processes like cutting, turning, drilling and taping. The constant metal deformations such as stamping and shearing operations are used to make cross corrugated fin. The method and sequence of manufacturing process followed is shown in flow chart – 1.

7.1 DIE SETS

The top and bottom die blocks were initially machined using conventional machines with required allowances for grinding. After getting the required die shapes the blocks were hardened to get the required hardness. The exact shape of the die blocks were obtained by wire EDM processes by feeding the geometry in machine preprocessor as AUTOCAD DXF format. Then they were ground to get the final dimensions. The locating pin holes and load bearing pin holes on both top and bottom blocks were drilled using spark EDM by feeding the reference co-ordinates in the machine preprocessor. The forming and shearing tools were milled to get the required size using wire EDM. The special jigs and fixture were fabricated and used to hold the form tool during EDM process. The surface finishing and grinding of all components were done to confirm to N4-N6 grade. All the die components were assembled. The single corrugated top and bottom die set is shown in figures 4a and 4b. The complete assembly details are shown in Figure-4c. The top and bottom double corrugated form tools are shown in Figure-4d. These form tools were used in the die set assembly to make the double corrugated fin. The required fin shapes were achieved based on the shape of the form tool. The die set has a facility to vary the tool shape to get the required geometry.

7.2 FIN FORMING

The assembled die sets were used to form the corrugated fins. The die set was placed in a 50 ton hydraulic press. The 0.4 mm SS sheet was placed between the top and bottom blocks. The required force of 14 ton was applied on the top die set to get the required fin shape. The formed fin was placed in a shearing die and the edges were trimmed by power press to get the exact size of the fin. The final single corrugated fin obtained after forming and shearing process is shown in Figure-5a. The same procedure was used for getting double corrugated fin geometry. The double corrugated fin geometry obtained is shown in Figure-5b.

Figure-5a Single corrugated fin

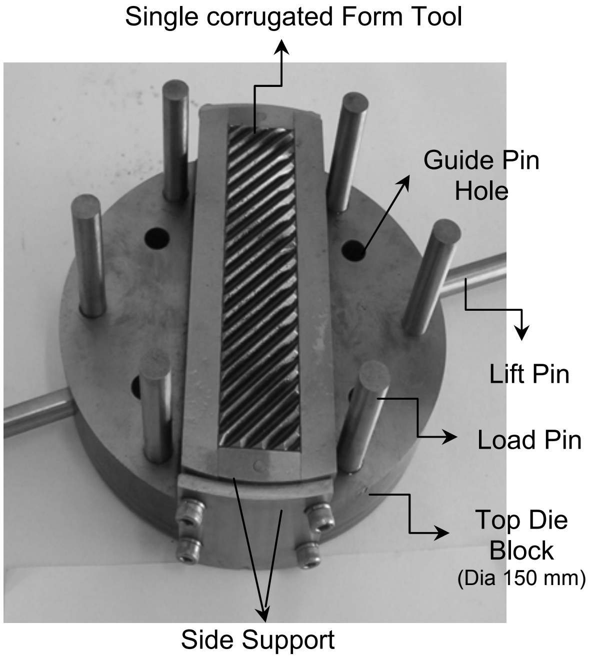


Fig. 4a Top Die

Fig. 4c Multi-configured Die Set

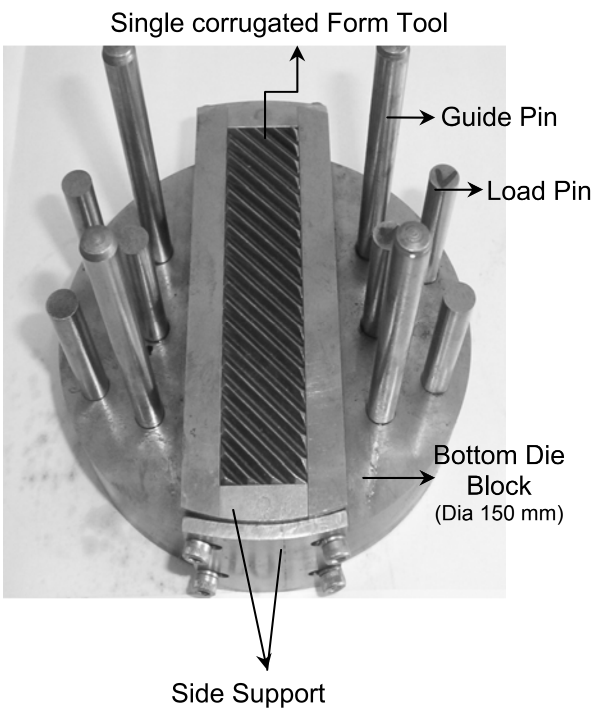


Fig. 4b Bottom Die

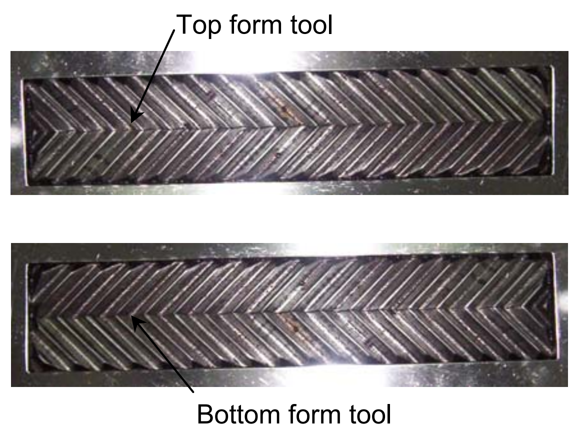
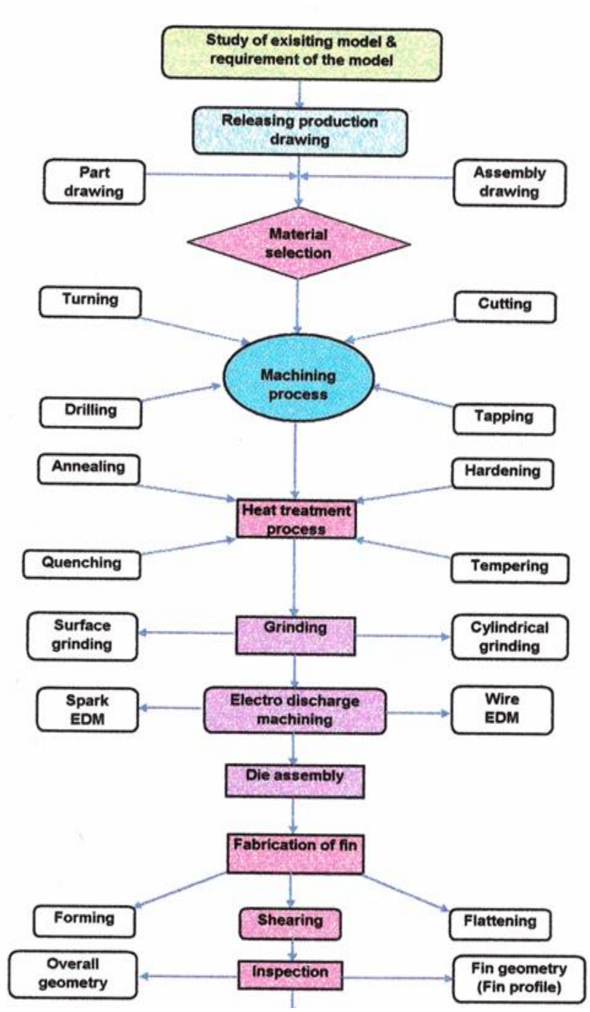


Fig. 4d Top & Bottom double corrugated form tool

Figure-5b Double corrugated fin

FLOW CHART – 1 DIE SET AND FINS MACHINING PROCESS/EVALUATION



8. CONCLUSIONS

The multi-configured die sets were successfully designed and fabricated to form annular recuperator fins. All manufacturing accuracy requirements were achieved to form and shear the fins. The formed corrugated fins were qualified in a series of testes and large number fins were formed to use in the annular recuperator of the Micro gas turbine.

9. REFERENCES

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