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Design and Analysis of T-Shape Dovetail for Improvement in Peripheral Velocities

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Abstract

From the olden days in synchronous machines for attaching mechanically pole windings to the shaft dovetails are used. In general T-shape or Hammered head section is used as type of dovetail. Hammered head dovetail is a modification of T-section. Now a day there is a lot of demand for the Steam turbo generators. These synchronous generators require high runaway speed. High speeds can be achieved by using the forged shafts or by using high strength material for the punched spiders. Forged shafts are economically not preferable due to reason of more lead times and costly machining processes etc. Laminated spider type shafts are used in some cases. It is limited by the strength of the material, i.e. limitation in getting high strength material economically is difficult. To overcome above constraints Modification of dovetail section could be the one of possible solution to overcome above constraints for a high peripheral velocity. This is explained step by step in this report, from developing base line for the T-section dovetail model to possible modifications into new geometric models. Percent of improvement in peripheral velocities are calculated with respect to base model.

Keywords: Dovetail, Peripheral velocity, Shaft, T-Section.

Introduction

Now a day as the demand for the electricity is increased, Steamturbogenerators have become very important. These are rotating machinery equipped with electrical components to generate power. As these have rotating machinery equipment, it should satisfy the mechanical design criteria's in manufacturing and design point of view along with the satisfying the electrical requirement. This can be clearly understood with the help of fig-1,

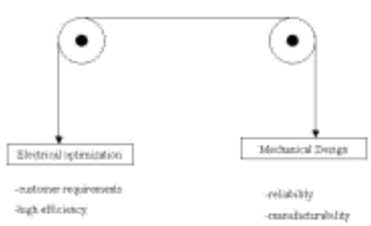

Fig-1 Electrical-mechanical interaction

Generally electrical machine design is the complex of calculations, optimization. It is necessary to have experience and knowledge to accomplish correct machine design. In the design of motors and generators, the first step is to design the active materials or in other words, design of the stator and rotor cores. In Electrical rotating machines, the stator core consists of coils, punching, space blocks and wedges. The rotor core is quite different on an induction and synchronous machine. In an induction machine, in general, the core consists of punching, space blocks, flanges and a squirrel cage winding. A synchronous machine consists of punching, amortisseur winding, rotor field winding, endplates, tie bars, top sticks or collars and coil brackets. The design of the rotor and stator cores is commonly known as "electrical" design. As stated above, it includes mechanical designing of the parts. The electrical design of these rotating machines is nothing but the assembling of a group of mechanical parts that fit together. In assembly to the shaft pole with copper windings are attached through the dovetails. These copper coils may be strip wound or coil wound based on the time and economic factors. On the poles there are some accessories like end plates, dampers etc.

Poles and spider Shafts are connected by means of mechanically through the dovetail. As these parts are made of various material these should satisfy the basic principles of mechanical engineering.

For better understanding the of synchronous machines rotor section, figures are shown in below.

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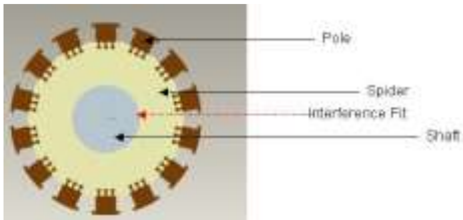

Fig-2 Assembly section of Synchronous machine rotor

Designed point of view pole and spider assembly plays an important role. The enlarged out portion of the pole is shown in fig-3.

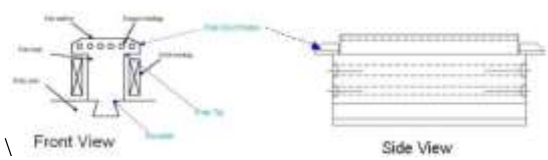

Fig-3 Pole with accessories

The dovetail shapes using presently in these machines are known as T-section and Hammerhead section. To achieve better speeds with these dovetail sections, material with high strength to be selected. From cost point of view going to high strength material is not so preferable.

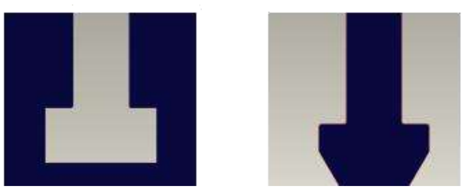

Fig-4 Section of Dovetail shapes

Dovetail shapes what presently using is shown in above fig. Based on the loads on poles, the neck size and number of necks are selected. Dovetails to withstand for high peripheral velocity more necks can select. But it has some limitations like limited across flats distance, core outer diameter, etc. So for better peripheral velocity and to improve the stresses dovetail design to be modified. Classification of dovetails is as follows based on respective designs

Based on Shape

T slots

Hammer Type Slots

Based on Size:

0.75T; 1T; 1.25T; 1.2T

Importance of Dovetails:

Dovetail plays an important role in the assembly of rotating parts in electrical machines. Here few points are given below about the importance of the dovetails

To provide the mechanical support (holding the pole).

To carry effectively the electromagnetic flux generated by the rotor winding.

To ensure the perfect linkage between pole and rotor yoke.

Generally dovetails are made by punching operation, thickness ranging form 0.5 mm to 10 mm.

Description of Dovetail Stresses:

Dovetails are in T shape; the stress patterns in theses dovetails are not uniform throughout the area. High stress is at the sudden change or at discontinuity in the geometry of section. That is at the fillet of the dovetail. The high stress at fillet area zone is due to concentration of stress flow lines in more and it's due to discontinuity in the geometric profile of the section. To decrease the stress concentration at fillet, radius can be increased.

To operate at higher peripheral velocities without changing the material, design to be modified. This is one of best possible way for getting better peripheral velocity. Increasing in the dovetail depth leads to decrease in the stress of pole but it will show effect on spider. To solve these problems, a model without changing the depth of dovetail can be modeled.

Dovetail Selection

As the first step in the design synchronous machines dovetail, is the selection of suitable dovetail. This could be done as follows. As a first step calculate the centrifugal force due to rotation of pole. Centrifugal Force depends on the radius of rotator (Rotor outer diameter), peripheral velocity of machine and pole weight. For the selection of suitable dovetail size and shape to satisfy mechanically at given rotating speed, first calculate
neck load.
The neck loads can be calculated as
follows

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The below data is from Base Model-1

Radius Of rotation ~ 1137mm
Rated Speed = 360 RPM
Over Speed = 740 RPM

Weight of Finished pole=784kg=1728lbs

Pole length (along shaft)=1011mm=39inch
Centrifugal Force (Per Cross section) per inch==29869.7908Lbs(@ Over Speed

Neck Load per inch (for 1.25T)= =23895.246 lbs/inch
Based on the available material and standard guidelines, M7301A6 is chosen as the suitable material. It has the neck load limit of 31800 lb/inch. If the force per inch is more than limiting value of material then multiple necks is opted. But it is limited by the width of the spider and pole. And it can be related as follows

No. Of necks α Sector Area

When there is need to increase no of necks, need to think about the effect of forces due to each other and on other poles also, i.e. minimum distance between two adjacent necks. For deciding the failure of design yield strength of material with 2/3-limit value is considered.

Analysis of T-section Dovetail

After selecting the suitable neck size, next step is analysis of dovetail for the limiting stresses at critical section. For analysis consider the some of the previous manufactured models and results of these machines are used as benchmark for the further implementation of the dovetail section. Comprehensive analytical calculations are done on the manufactured models and those are validated with ANSYS. For simulation in ANSYS the model is generated in Pro-e and imported to ANSYS.

Table: 1 Analytical and ANSYS stress values comparison

	Vonmises Stress in pole (Mpa)			
	Nominal stress		With Stress Concentration Factor	
Base model	Analytical	Ansys	Analytical	ANSYS
1	164	160	671	667
2	48	57	240	231
3	126	123	516	499

Conclusions about T-section Dovetail:

Table: 2 Comparison of Stresses in a set of working Models

Vonmises Stress in pole(Mpa)	Analytical	ANSYS
Nominal stress	163.82	166
With Stress Concentration	671.96	664

T section is very good to resist bending stress.

Zone of nominal Stress spread is good.

Stress concentration zone is very limited as radius is small.

Due to Sudden change in the geometry of T dovetail it will cause more stress at fillet section and this will lead to plastic deformation.
From the above analysis, as worst-case condition Base model –1 is considered as benchmark for the further implementation of the dovetail geometric section

Concept for modeling new Dovetail Shapes
Possible modified (alternate) Shapes & Details
To reduce the stress at sharp fillets, the design can be modified as shown in below. As shown in fig-5 the T section can be modified.

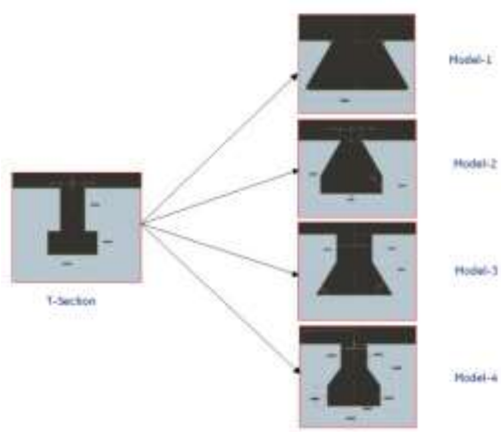

Fig: 5 Possible Modifications for T slo

Model-1:
As shown in the fig. it's a v section. The possibility of failure in this section is only due to tensile stresses. This failure will occur at the neck of dovetail. The load carrying capacity is less when comparing with the other models due to the resisting material is less

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when comparing with other models for same neck and base width condition. Due to this reason there are more chances of opening of neck. Digging more depth in spider can reduce the displacement. But it will weaken the spider.

Model-2:
It's an improvement of the model-1. By providing some more material at the bottom width as shown in fig, the chances of escaping the pole from joint are less. This is due to bending of the excess material shows this effect. The stresses are less when comparing with the model-1. In this model there are two points, which are critical for the failure section. One is neck and other is at the angel corner. In this model, there are more chances of failure in spider than pole, due to less resistance material than pole or same resistance material as model-1.

Model-3:
This is another type, which will reduce the stress concentration at corner (fillet). This is similar to the previous model but the material distribution is different. It will show good strength for the centrifugal forces by providing the sufficient material. In this model also two critical sections are present similar to previous model. This model will fail not only due to tensile and bending forces as previous model but also with shear force components. Some of the sections of failures are shown in fig-6

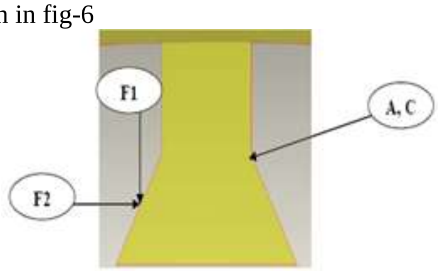

Fig: 6 Section of failures of Model-3

As shown in fig. the location of points of A and C are same but failure types are different. One is principal stress and other is shear stress. F1 and F2 are resolved forces of total centrifugal force.

Model-4:
As shown in above group it's a one more possible model, which will reduce the stress concentration. It's more rigid for shear failure than base model (T section). Because section of shear increases and highest among the entire models mentioned above. Failures sections in this model are similar to model-3

Possible failures in above models
As motioned above, these models will decrease stress concentration, and in addition to neck failure buckling of sides and localized yielding will takes place as shown in fig.

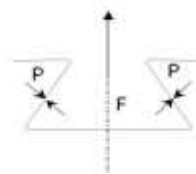

Fig: 6-a Failure due to Buckling

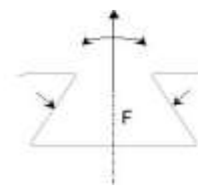

Fig: 6-b Failure due to Localized Yielding

Selection of better design by using the ANSYS simulation results
Results at over speed limit (77rad/sec) are shown below.

Table: 3 Set of results of Model 1-4 along with Base model

Pole	***Vonmises Stress (MPa)***	***Displacement (mm)***
Base Model-1	***390***	***0.216***
Model 4	***308***	***0.23***
Model 3	***370***	***0.268***
Model 2	***362***	***0.308***
Model 1	***-***	***>>***

From the above set of results it can concluded that model 4 is giving better stresses at over speed. Further optimized design for Moedl-4 is done later by using DOE. At over speed (77 rad/sec) with the model-1 type dovetail it's difficult to resist the centrifugal forces generated in dovetail due to rotation of pole. I.e. yielding in the dovetail is more and pole come to outside. So, due to this reason the stresses in model-1 are considered for comparison. Based on the Vonmises stresses the order of better models is given in ascending order.

Base Model < Model-3 < Model-2 < Model-4

Comparison of Analytical and ANSYS stresses.

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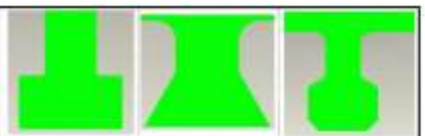
Table: 4 Comparison of vonmises stress of Base model and Model-3

	Vonmises Stress in pole (Mpa)	
	Nominal Stress	ANSYS
Base Model	136	390
Model-3	155	370

Comparison between old & new dovetail sections Stress comparison and % of Improvement in peripheral velocities:

The results of Model-3&4 are discussed with respect to Base model-1. The stresses calculated for the base model are at 77 rad/sec (740 RPM). At same RPM nominal stresses are calculated for the modle-3&4 by using the EXCEL sheet. The nominal stresses in this model are less when comparing with the base model. With the help of Excel tool and by trail and error method the maximum speed that can be achieved for the model3&4 are found. Here the maximum stress is equal to nominal stress of base model at 77 rad/sec (740 RPM). Comparison of Base Model with the new Model-3&4 in respect of stresses is done below. For comparison let consider the stresses at the fillet

Table: 5 Table of Comparison of stresses at fillet



	Base Model	Model-3	Model-4
Vonmises Stress @ 77rad/sec	164	155	120
Stresswith Stress Concentration factor	667	330	308
Speed can increase		164@80 rad/sec	164@90 rad/sec
% of increase In speed		4	17

So from the above table, the order of dovetail by strength wise is mentioned below. Model-4> Model-3> Base Model

Calculation of advantage from material side:

The yield strength of the material used for the base model has 45,000 psi. There is a lot of improvement in the strength of the material. Presently 66,000-psi yield strength material is available. If this material is used for the punching, then the machine can run to better speeds than previous. This can be find by using the excel tool and equal to 43% with model-4 when comparing with base model-1. It means that by using new strength material and new modified dovetail section (Model-4) the possible improvement in peripheral velocity is 43%. Here all the conditions are maintained same with respect to base model-1.

Note: The stresses considered for the failure decision is with factor of safety only, i.e. 2/3 of yield strength. Same factor of safety should consider at over speed also. If the limit value of factor of safety is decreased at the over speed, there is a chance of achieving high peripheral velocity. This could be an added over advantage. But it mainly depends on the purity of material.

Conclusions

The aim of this paper is achieving of more peripheral velocity by modifying the profile of the geometry of dovetail section. For fulfilling this task a systematic procedure is followed from the analysis of base models for reference purpose and to finalizing of new dovetail section. This is explained in the previous sections. And brief summaries of set results are concluded here.

Model-3

Conditions:

Same neck load or same neck width.

Bottom width is also maintained same.

Machine is similar to base model-1 machine except at profile of dovetail section

Conclusions:

4% improvement in peripheral velocity is possible. This advantage is only from the design modification side.

If the advantage from better strength material is considered, then the total improvement in peripheral velocity due to modified dovetail section and advantage of improvement in strength of material is 20%.

Advantages:

This modified section has some advantages over the T-section. For the same neck width the depth of the dovetail is less and almost 0.65 times less depth. So it’s an added over advantage for the spider in strength wise.

Disadvantages:

As on increasing the depth of dovetail, it’s limited to less no. of necks. It’s due to that for same neck width and optimum slant angel width of bottom edge becomes more.

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Model-4:
Conditions:

Same neck load or same neck width.

Bottom width is also maintained same.

Height of the new section and T -section dovetails is same.

Machine is similar to base model-1 machine except at profile of dovetail section

Conclusions:
17% improvement in peripheral velocity is possible. This advantage is only from the design modification side.

If the advantage from better strength material is considered, then the total improvement in peripheral velocity due to modified dovetail section and advantage of improvement in strength of material is 43%.

Advantages:
As previous model it not have any constraint on the width of the dovetail section. These dovetails can replace with T-section. It’s due to both had same neck width, height and also bottom width.

Disadvantage:
As this section contains slant edges machining allowances should be provide equally on both sides.

Scope for the Future work

Instead of T-section dovetail, new dovetail section shape can be used for high peripheral velocity with safe design limits. There are still more chances of increasing the strength of the design by knowing the some more properties. For this some work has to be done. The future work can be carried out on the modified section for the further improvement in the peripheral velocity is mentioned below.

Multistage Dovetail: The dovetail section can be modified into multi stage or multi level. Care should be taken while dimensioning because tolerance limit will effect on the stresses of the multi level.

Fatigue Stress: As this is a rotating member, chances of failure due to fatigue are more. For better judgment about the dovetail section fatigue stress calculation should be carried.

Behavior of material in plastic zone: There are local plastifications observed. The difference between the nominal stress values and stress at discontinuity geometry (Plastic zone) is more. This will show effect on the material behavior. Due to this the properties of the material will change abruptly. So a great study should be carried out on this. The behavior of material in the plastic zone is clearly mentioned in Dynamic Plasticity