A Tubular Hydro-Generator Through Bolts Failure Analysis

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Abstract: After running for several years, in the maintenance of a tubular turbine, many through bolts melted, and fatigue fracture, insulation damage were found. First, an analysis is done. Then simulation calculations are done to investigate the additional losses and the electromagnetic force acted on the through-bolts. Finally, the modal is analyzed. The results show that after long-term operation, under the action of the electromagnetic force vibration, fatigue, deformation, short circuit to stator core is formed with key bars, and a lot of heat is generated. That' s the reason how the accidents occur. At last, treatment suggestions are proposed. A year after the treatment, the bolts condition are examined and it shows they running well.

Keywords: hydro-generator; through-bolt; melting; finite element; fault diagnosis

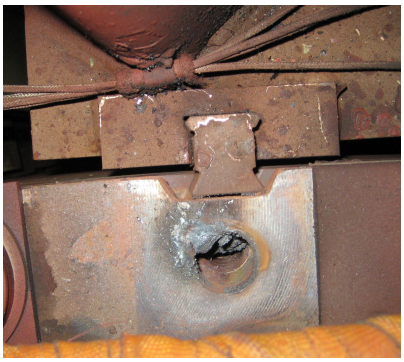
0 Introduction

After running for several years, in the maintenance of a tubular turbine, melting, fatigue fracture, insulation damage were found in some through bolts.

According to the inspection, 32 bolts with insulation failure; 21bolts with the insulation resistance value zero; eight screws in 132 screw were melted. Phenomena has the following characteristics:

1) The melting bolts distribution has obvious pattern as they are opposing the key bars.
2) Leaked oil found on bolts
3) Some key bars are over heated.
4) Fracture is transverse fatigue fracture.

Fig 1. Melted key bar



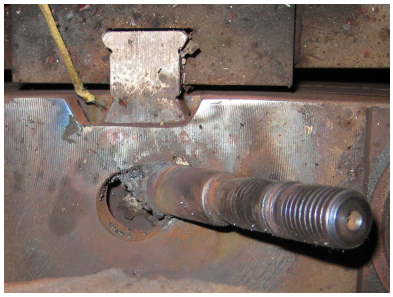


Fig 2. Melted through bolts

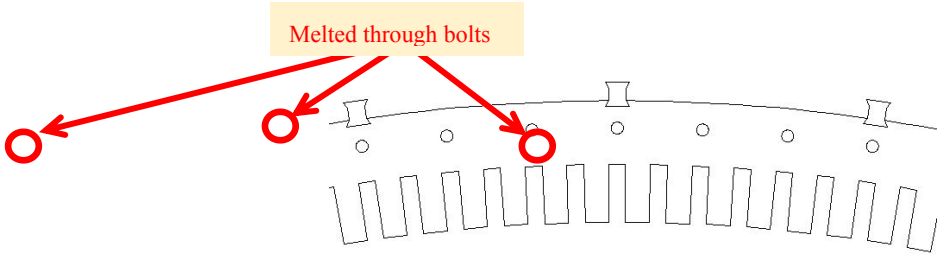


Fig 3. Melted key bars Distribution

1 Basic analysis

According to the investigation, it seems large force was applied to the damaged bolts. After operation for years, the fatigue fracture formed. At the meantime, large loss generated in the bolts and the bolts melted. The possibility is that after the through bolt insulation damaged, the through bolts were short circuited with the key bars at the back of stator core.

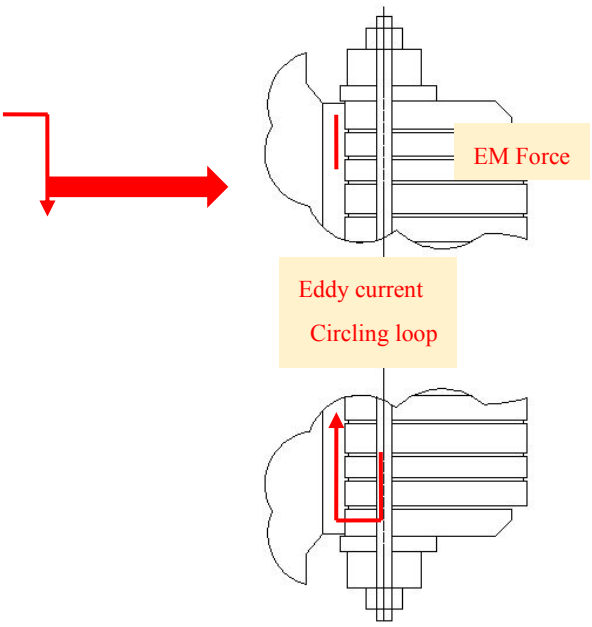


Fig 4. Short circuit passage

So, the EM force and eddy losses are analyzed for both Short-circuit and open circuit condition.

1.2 Basic principle

When short circuit happens, large current and EM force will be generated in the through bolts. If the force frequency is near the natural frequency, it will cause big vibration.

The Laplace force density can be expressed by the current density and the flux density on a point:

$$d\overrightarrow{F_L} = \vec{J} \times \vec{B}$$

The Laplace force acted on a volume region can be expressed by:

$$\overrightarrow{F_L} = \int_V (\vec{J} \times \vec{B}) dv$$

After we get the current density distribution, we can get the loss density:

$$p = \left|\vec{J}\right|^2 \times \sigma$$

As the same, integration of the region loss density is the region loss.

The most serious condition is that the through bolts are short-circuited at the end parts with key bars and core. And the Electromagnetic field is analyzed with Jmag designer.

2 No load analysis

Both the normal condition and insulation failure condition are analyzed for no load operation.

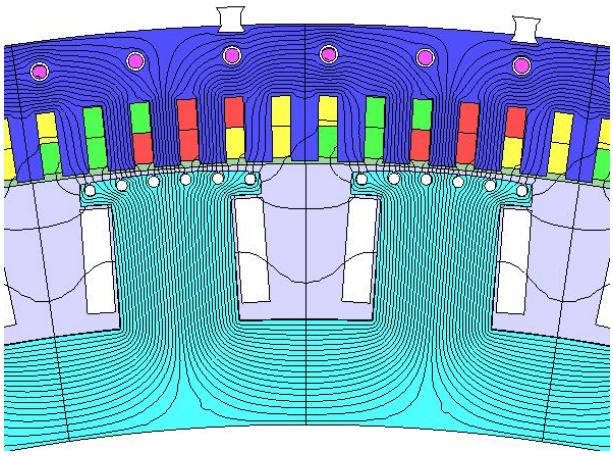


Fig 5. Magnetic flux line distribution at no load condition with good insulation

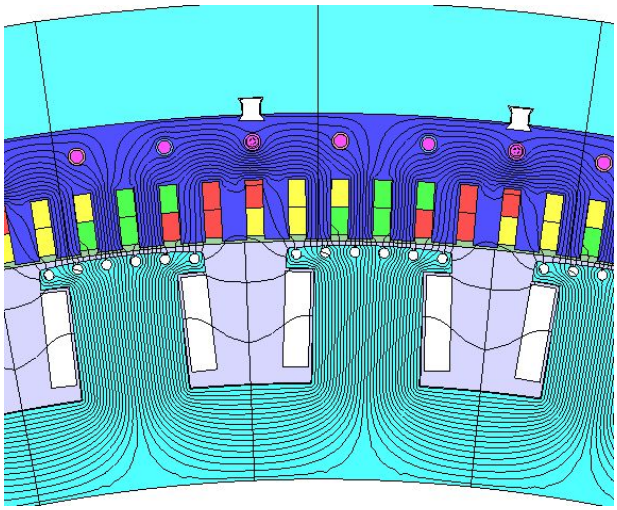


Fig 6. Magnetic flux line distribution at no load condition with failure insulation

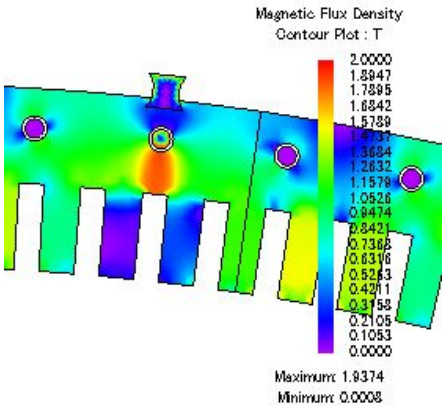


Fig 7. Magnetic flux density distribution at no load condition with failure insulation

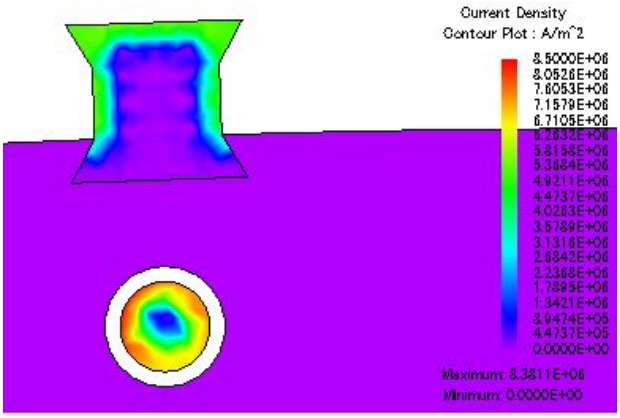


Fig 8. Eddy current density distribution at no load condition with failure insulation

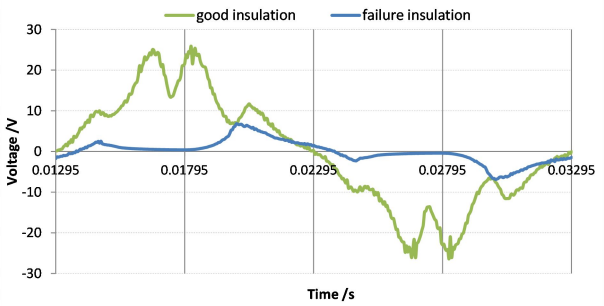


Fig 9. Through bolts induced voltage

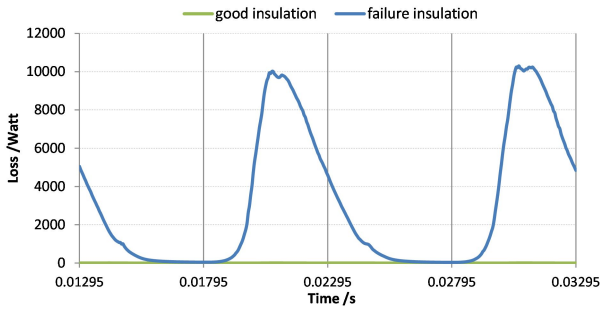


Fig 10. Through bolts eddy losses

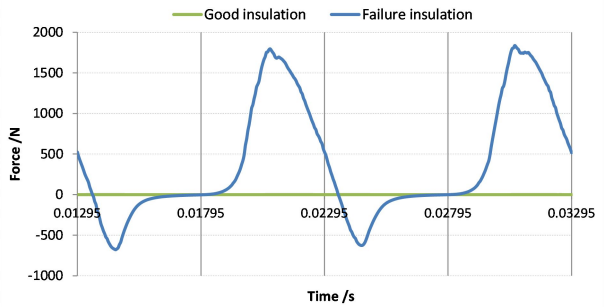


Fig 11. Through bolts eddy losses

According to the vibration analysis, as the pre-tightening force gradually decaying, the second order natural frequency would be reduced from 138Hz to 99Hz. That means, after long term operation, because of the core vibration and hot-cool cycling, the natural frequency will be decreased to 97Hz at last.

As the electromagnetic analysis, the EM force acted on the bolts is mainly 100Hz, which will cause large vibration in the bolts.

3 Rated load analysis

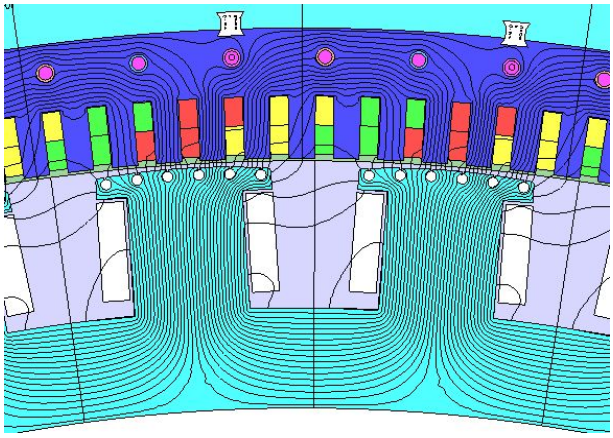


Fig 12. Magnetic flux line distribution at rated load condition with failure insulation

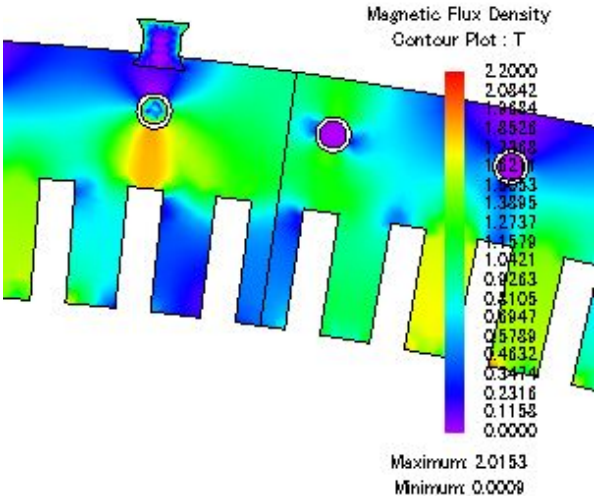


Fig 13. Magnetic flux density distribution at rated load condition with failure insulation

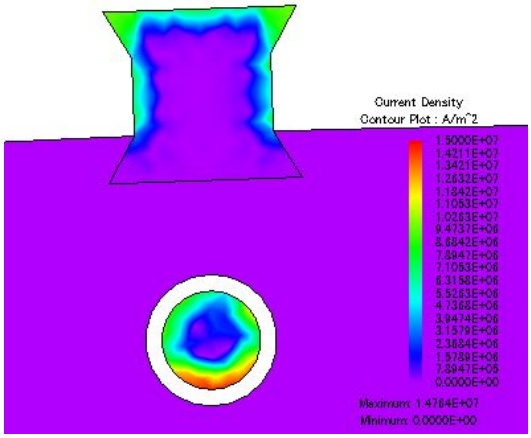
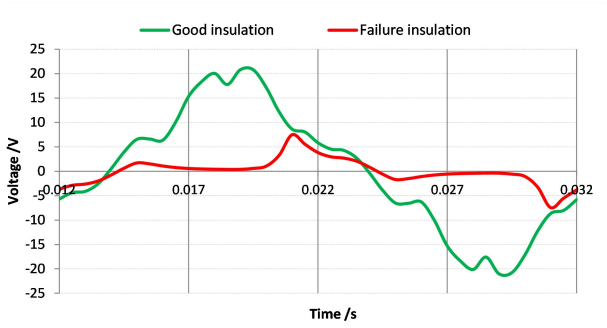
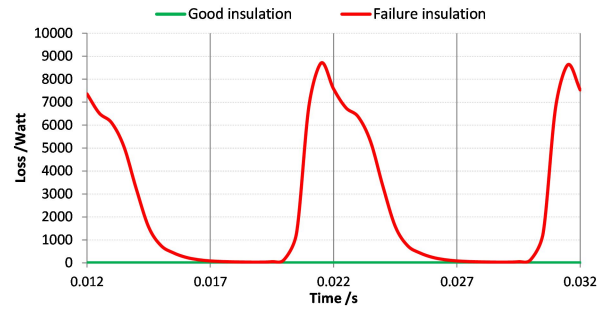
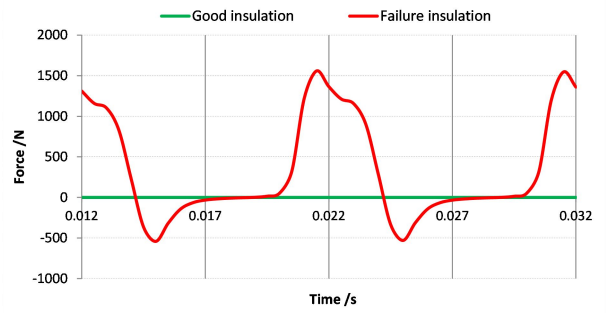


Fig 14. Eddy current density distribution at rated load condition with failure insulation







Tab. 1 Electromagnetic Calculation Results of the Through Bolts

Condition	No load		Rated load	
Insulation Condition	Good	Bad	Good	Bad
Voltage /V	13.20	2.71	12.37	2.64
Loss /W	1.43	3097.87	0.58	2457.61
Loss Density/ W/m^3	2.95E+03	6.39E+06	1.19E+03	5.07E+06
Loss Density proportion to coil	0.01	23.39	0.00	18.55
Electromagnetic Force /N	0.67	2514.48	0.24	2099.10

Calculation results analysis

1) When the bolt insulation is good, the eddy current and the electromagnetic force is negligible;
2) When the insulation fails, the eddy loss can be very high. At the most serious condition,

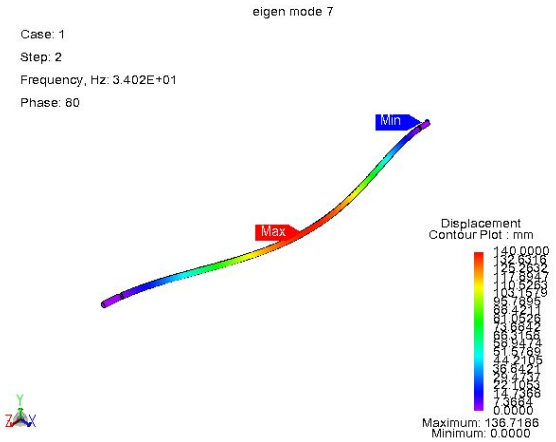
the eddy loss is about 3kW per bolt, and the loss density is about 22 times the stator coil value. The loss would make the bolts melt;

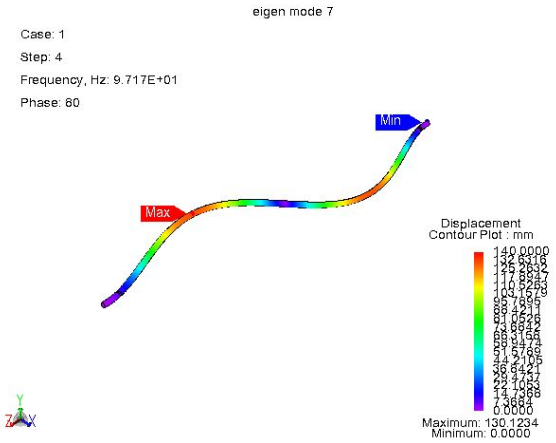
3) The electromagnetic force is mainly 100Hz, 2.5kN per bolt.
4) The bolts near the key bars are more easily short circuited which the key bars. So they are more likely to melt and broke.

4 Modal analysis

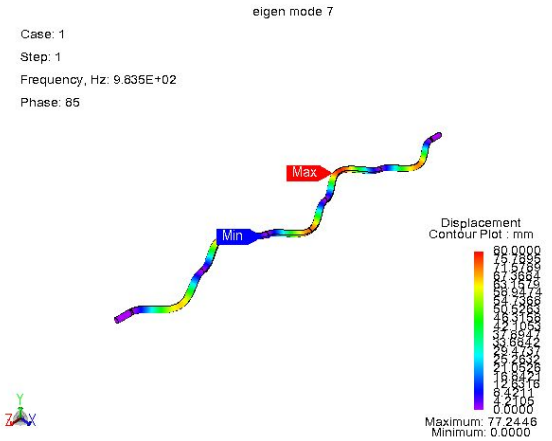
After the electromagnetic analysis, a modal analysis is carried out to examine the natural frequency.

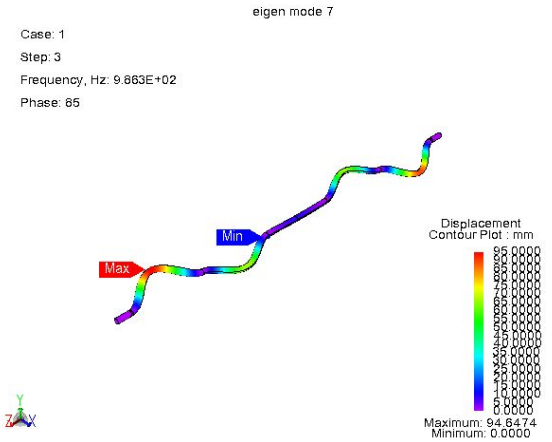
At first, the 2-support schemes is evaluated (means the bolts are fixed with the nuts at end part), the results show that the second order natural frequency is 97.2Hz. Based on the electromagnetic simulation, resonance will happen in the bolt.





Then, a 7-support schemes is evaluated (means except the end part fixation, the bolts are also fixed well with the core in active part), the results show that the natural frequency is higher than 983.5Hz, and it is far from the 100Hz, which is the EM force frequency.





Tab. 2 Modal Calculation Results of the Through Bolts

Scheme\order	1	2	3	4
2 supports	34.0	97.2	185.1	306.5
7 supports	983.5	986.3	993.5	1001

5 The failure reasons:

After the electromagnetic and mechanical analysis, we consider the failure reason as follows:

1) Several reasons cause the tighten force decreases, and the natural frequency is decreased near 100Hz, which stimulates the resonance and made the mechanical and insulation failure.
2) Oil mist has not been cleaned for years, which also cause the insulation failure;
3) As insulation gets worse and worse, the 2-point short circuit happens, then huge force and eddy loss are generated.
4) Vibration and failure insulation reinforce each other. Bigger vibration will damage the insulation, and worse insulation will generate bigger vibration and heat. Finally the bolts are damaged.

6 How to prevent this

Since the causes are found, several measures should be done to prevent this happening again:

1) Improve the bolt fixation to avoid 100Hz natural frequency.
2) Use thicker bolt insulation.
3) Fill the gap between the core and bolts with flexible material to minimize the vibration.
4) Improve the seal to reduce the oil mist.
5) Clean the oil mist regularly.