

A Tubular Hydro-Generator Through Bolts Failure Analysis

某贯流式水轮发电机穿心螺杆特殊故障诊断

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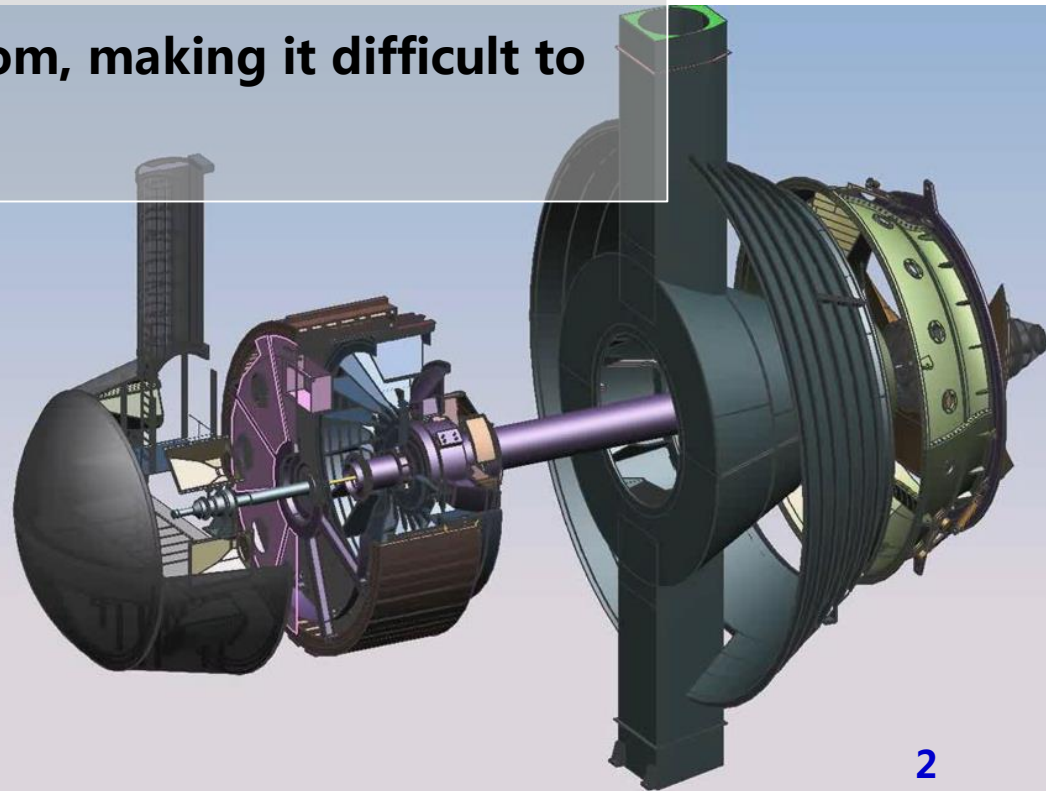
DongFang Electrical Machinery Co., Ltd.

China

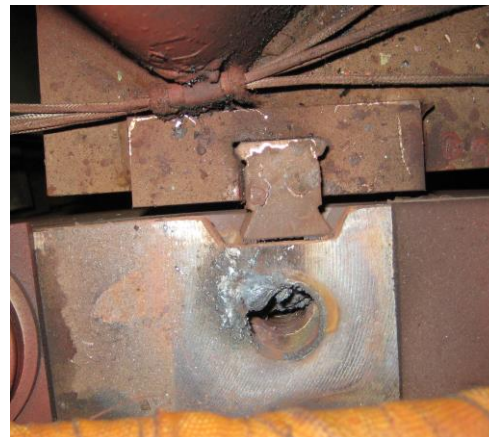
Nov, 2016

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- **Bulb Type Hydro Generator unit**
- **Making use of low water head flow and tide energy,**
- **Developed profoundly in china in recent years**
- **Low rotation speed, small room, making it difficult to design and maintain.**



- After normally running for several years, in the maintenance of a tubular turbine, lots of melted through bolts, fatigue fractures, insulation damages were found.



- **32 bolts with insulation failure;**
- **21 bolts with the insulation resistance value zero;**
- **8 screws of 132 were melted.**

Phenomena has the following characteristics:

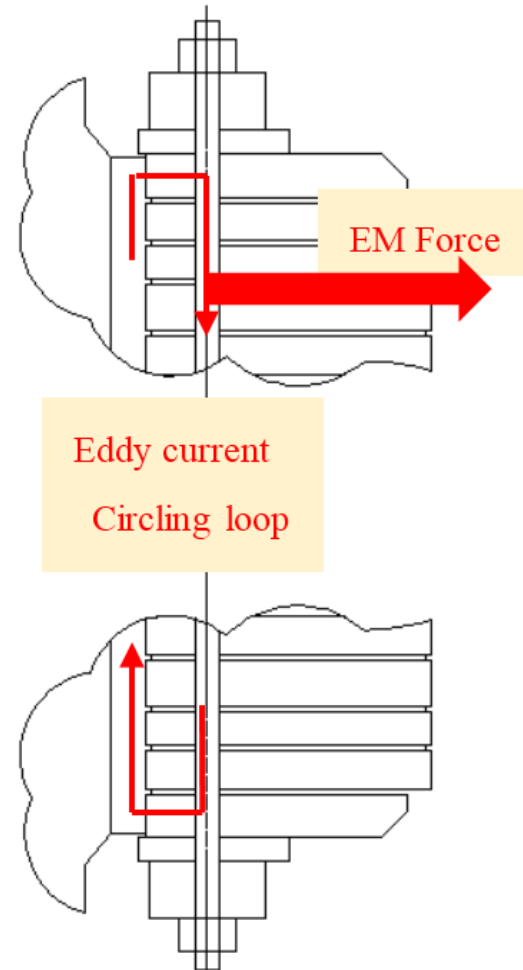
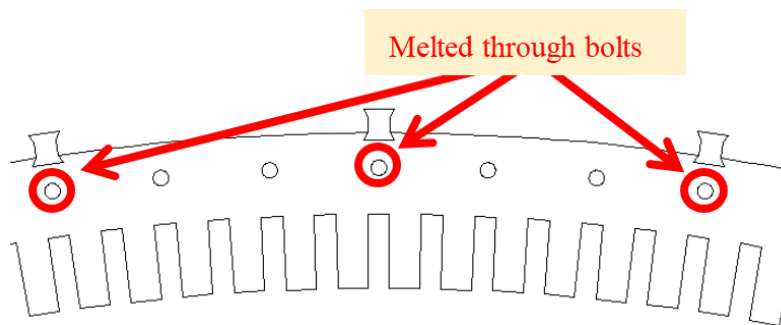
- • **ALL melting bolts are opposing the key bars.**
- • **Leaked oil found on bolts.**
- • **Some key bars are over heated.**
- • **Some fracture is transverse fatigue fracture.**

To find out the root cause of the failure:

Fatigue fracture ← Large force applied

Bolts melted ← Large loss generated.

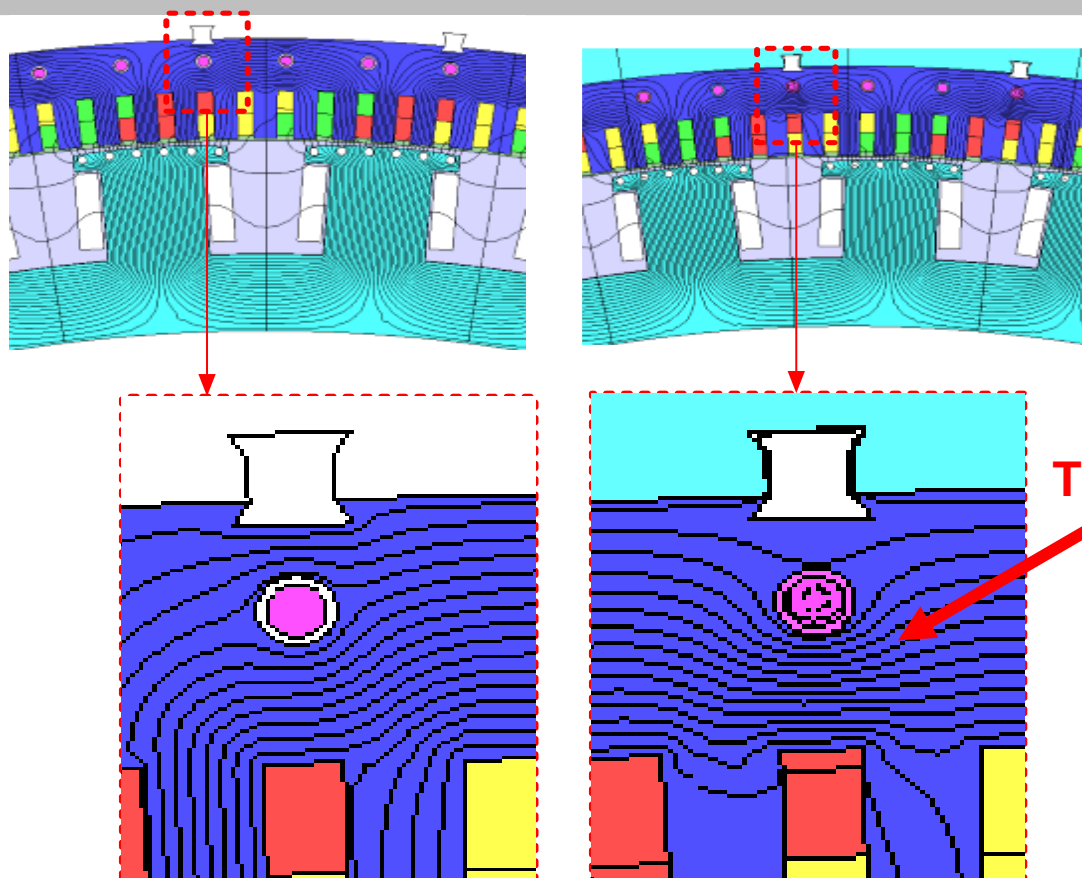
Through bolts short circuited with the key bars ?



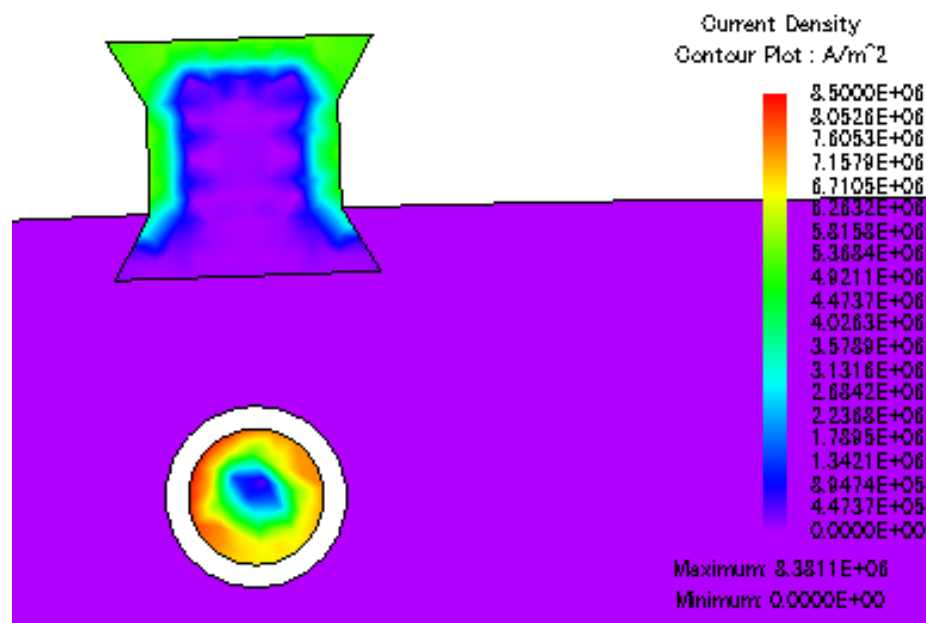
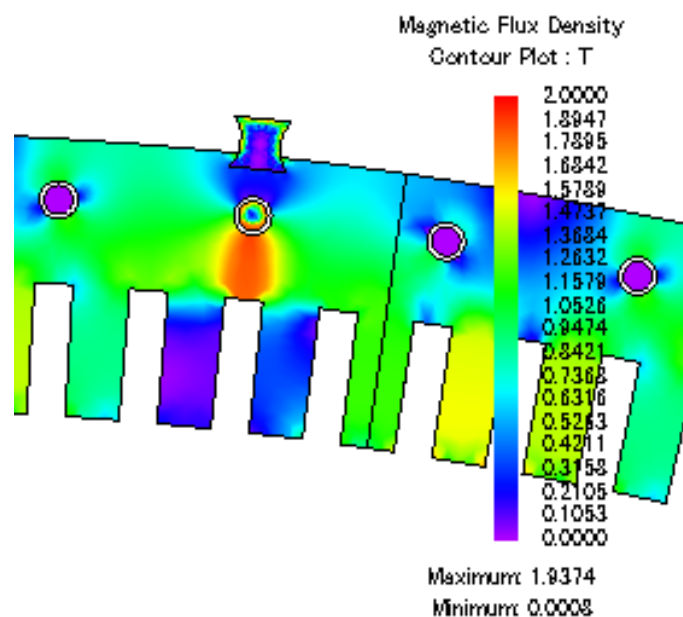
TO find out the source of large vibration and Loss:

- 1. Modal characteristic analysis**
- 2. EM force and Eddy loss analysis**

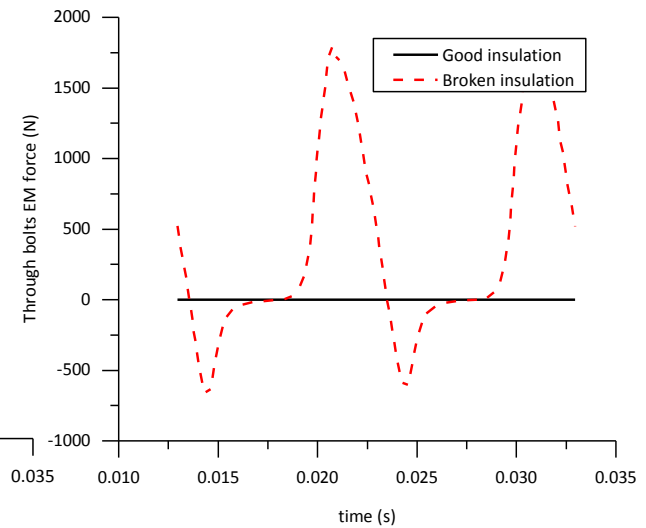
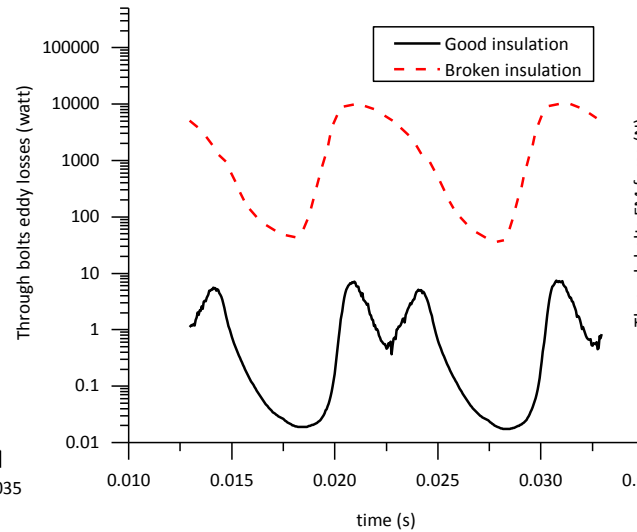
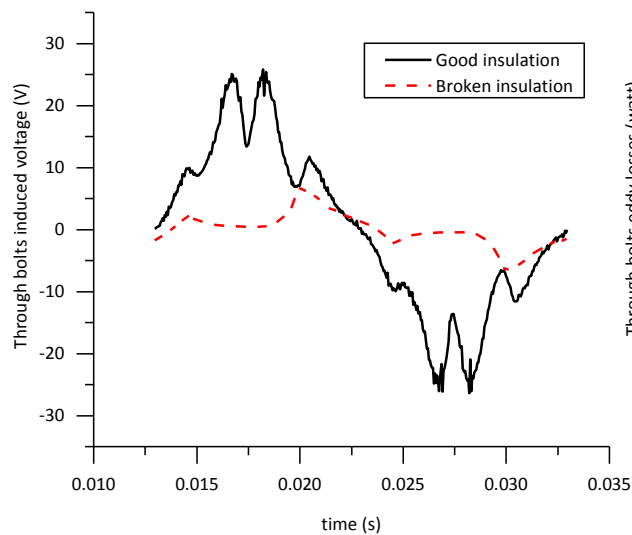
EM Field FEA: Flux line distribution before/after SC



Flux density & current density distribution at SC condition



Induced voltage/ Eddy loss/ EM force comparison between good and bad insulation of through-bolt



Calculation Result Summary:

Condition	No load		Rated load	
	Good	Bad	Good	Bad
Insulation Condition				
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

Conclusion of EM analysis:

- a) **Insulation fail leads to very high eddy loss and force. (3 kW and 2.5 kN per bolt in most serious situation)**
- b) **EM Force is mainly 100 Hz**
- c) **The bolts near the key bars are more easily short circuited which the key bars. So they are more likely to melt and broke**

Modal Analysis——with or without pre-tighting force

According to design specification, the through bolt should be pretightened with 3.8 tN. But during the long time operation, the vibration and heat-cool cycle makes the force gradually decrease.

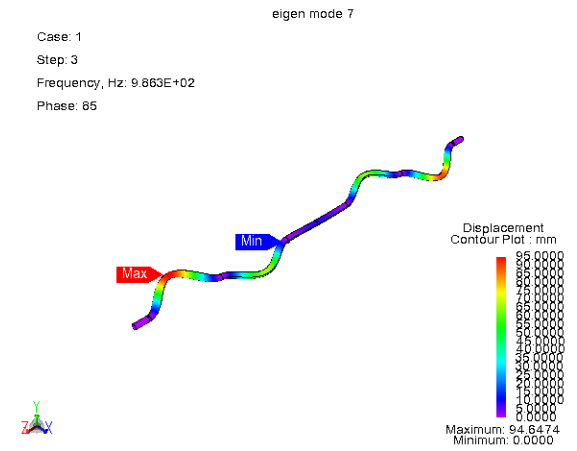
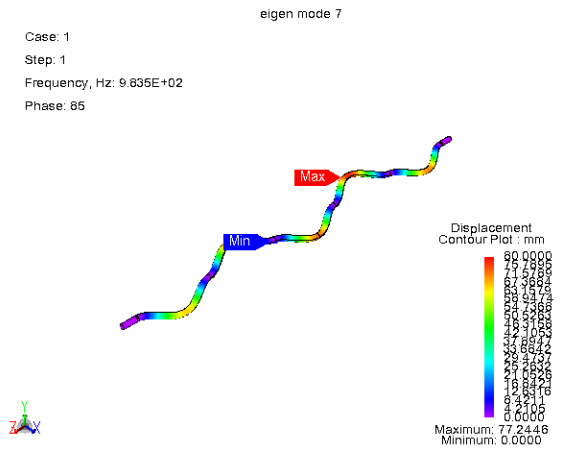
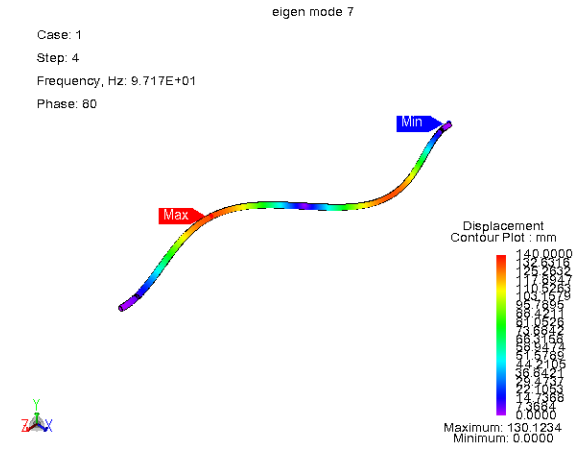
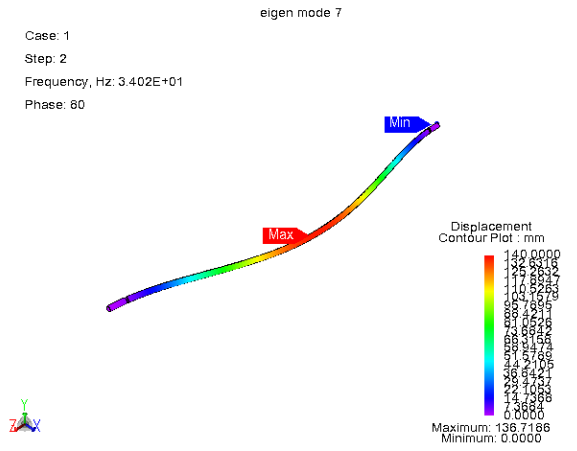
Condition	1 st order	2 nd order	3 rd order	4 th order
With pre-tighting force	34.0	97.2	185.1	306.5
Without pre-tighting force	55.2	138.2	225.0	351.3

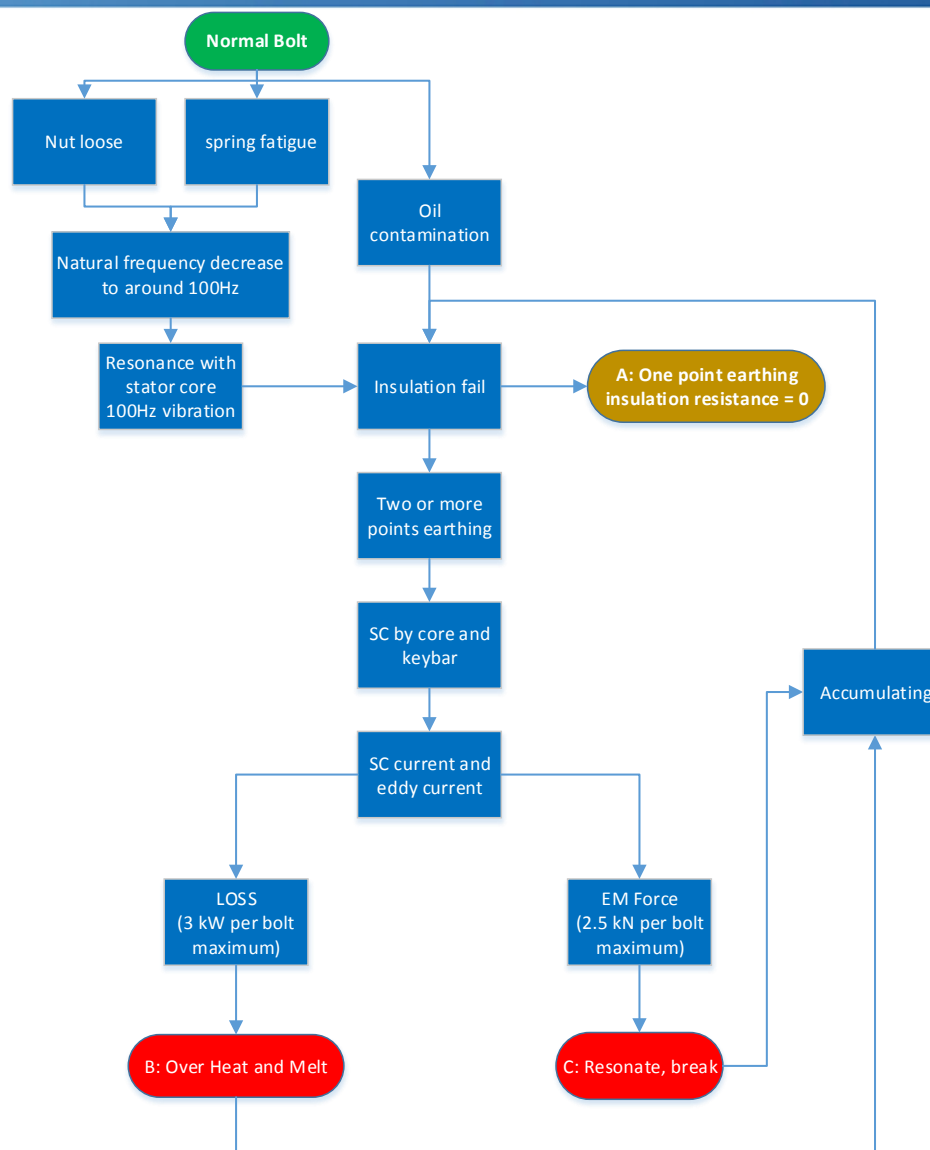
Modal Analysis——considering fix method:

1. Original scheme: air gap between bolt and core, lower natural frequency, more easily to vibrate
2. Optimized scheme: better fixation, much higher natural frequency, unlikely to vibrate

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

Modal Analysis—— different fix method:





Root cause analysis:

1. Pre-tighten force gradually decrease After long time of service
→ natural frequency drop to near 100Hz → easily resonate →
insulation fails
2. oil mist pollution → insulation fails
3. Insulation failure → 2-point short circuit happens → huge force
and eddy loss are generated
4. Vibration and failure insulation reinforce each other → Bolts
are damaged eventually.

Treatment:

- 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.**

Effect :

- 1. Two years operation after the treatment, the through bolts insulation performance was checked again, which was still in good state. This proved the measured were effective.**
- 2. This case provides useful information for generators design and relative failure diagnosis.**

Thanks for your attention !