40th Turbomachinery Symposium

Higher reliability of oil operated bolt tensioner for larger-sized steam turbine casings with higher inlet steam pressure

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Customer need for bolt tightening of steam turbine

Customer need = More safety maintenance working without heating operation

Necessity of using bolt tightening tool with explosion proof type

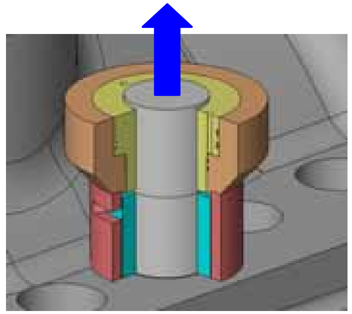
Applicable tool = Oil operated bolt tensioner

Tightening method :

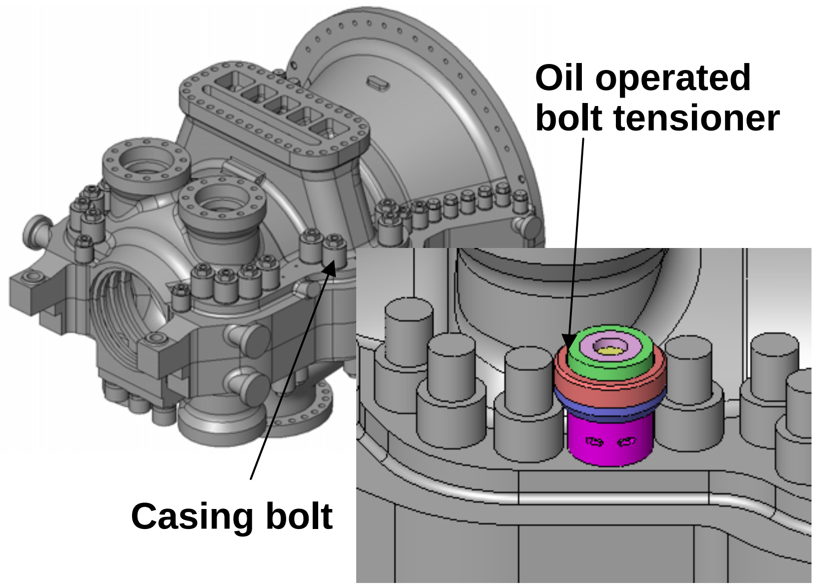
To extend and tighten bolts by hydraulic oil pressure

Note: a) Not necessary to heat bolt、b) Satisfied with explosion proof

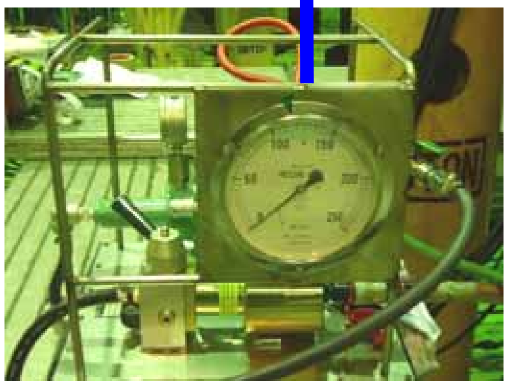
Bolt tension force



Cross-section



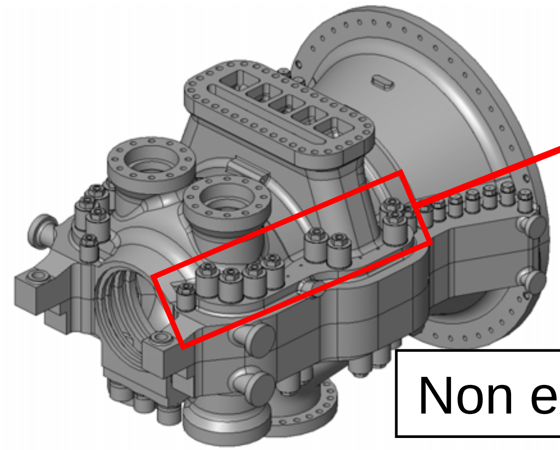
High-pressure oil



Oil pump

Tensioner

Classification of casing bolt tightening tool



Over M72 bolt size (Bolt diameter Φ72)

↓

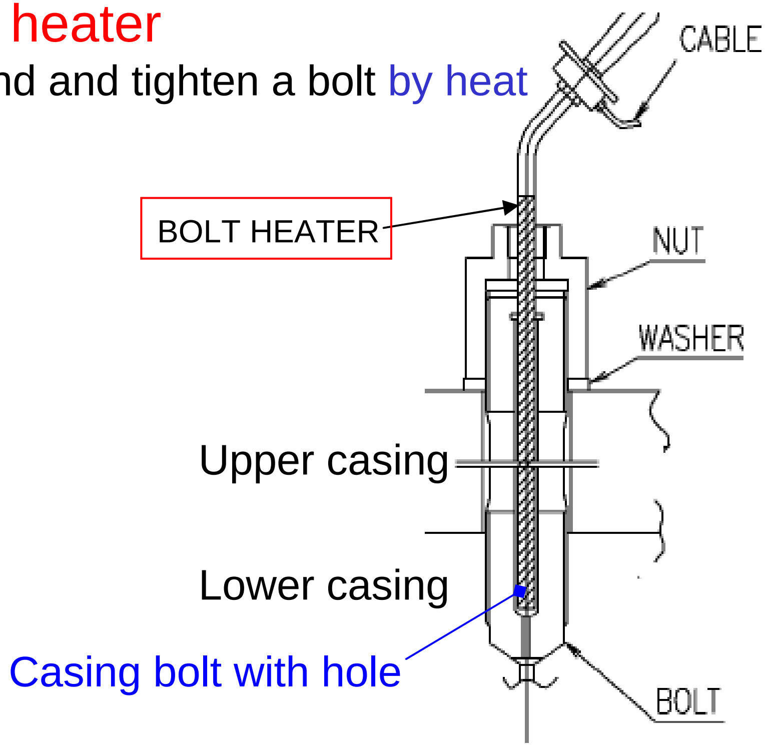
Use special tool for tightening

Non explosion proof type

Explosion proof type

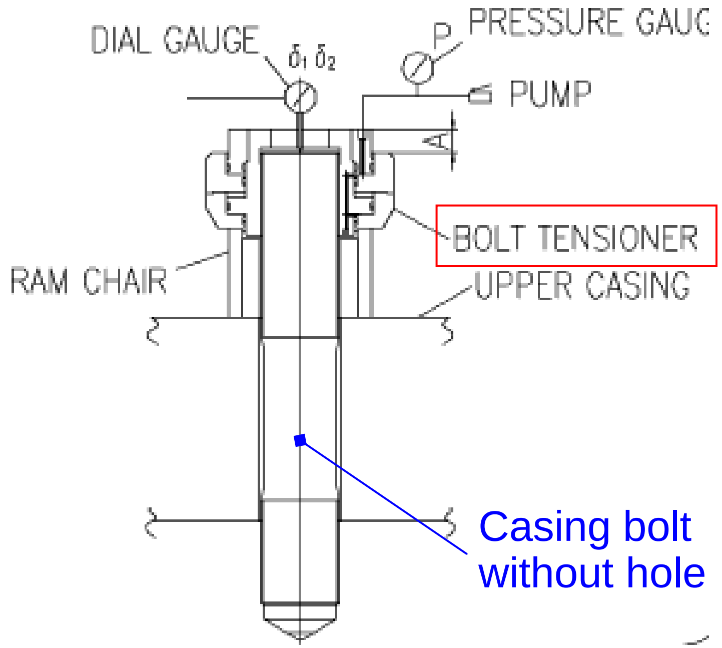
Bolt heater

Extend and tighten a bolt by heat



Oil operated bolt tensioner

Extend and tighten a bolt by oil pressure



Comparison of heater and oil operated types

		Coil heating type bolt heater	Oil operated types bolt tensioner
		Non explosion proof	Explosion proof
Function	**Working time**	**△(45-60 min/each)**	**○(5-10 min/each)**
	Work ability	**○(Weight : 1-2kg)**	**△(Weight : 30-50kg)**
	Life cycle	**△(Coil : Consumable)**	**○(Semi permanently)**
	Safety	**△(Heating operation)**	**○(High oil pressure operation)**
	Bolt pitch	**○(Narrow)**	**✕(Wide)**

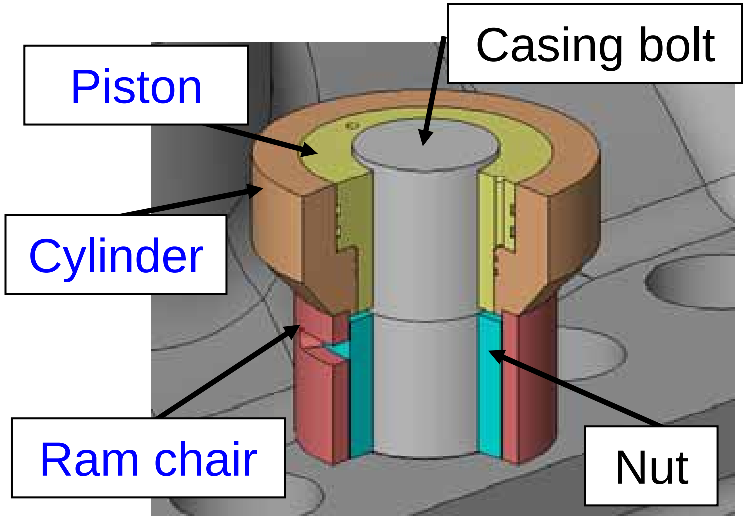
Advantages of Oil operated bolt tensioner;

1)Saving work-time

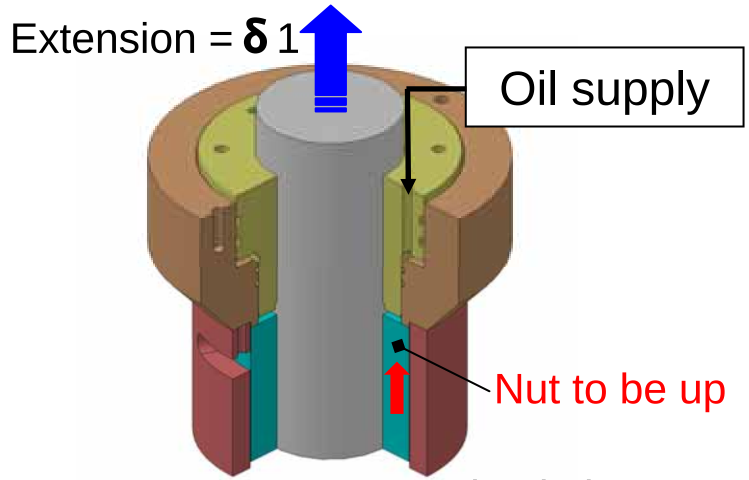
2)More safety working without heating operation

3)Reducing maintenance cost thanks to longer life-time in use

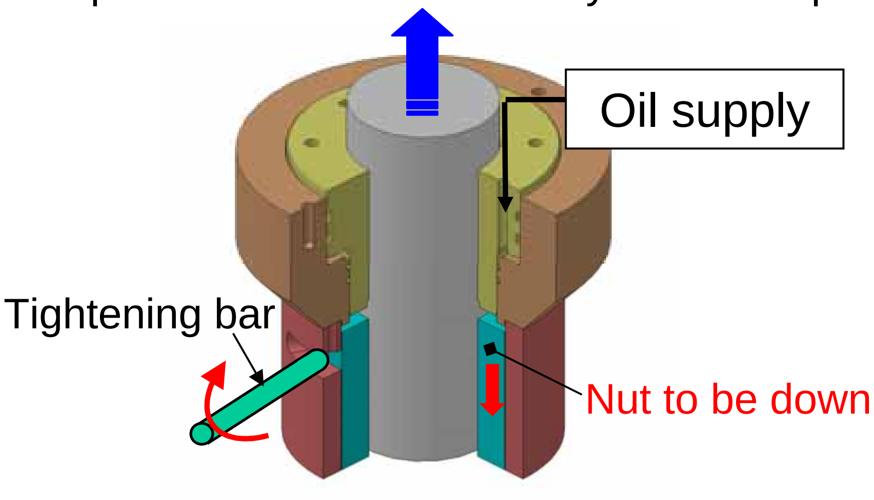
How to use oil operated bolt tensioner



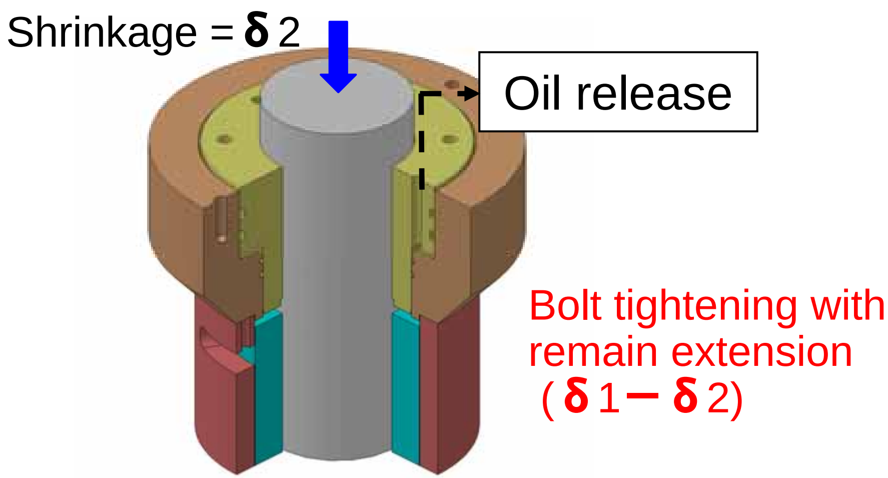
Step1. To set ram chair and cylinder with piston



Step2. To supply pressurized oil to extend bolt



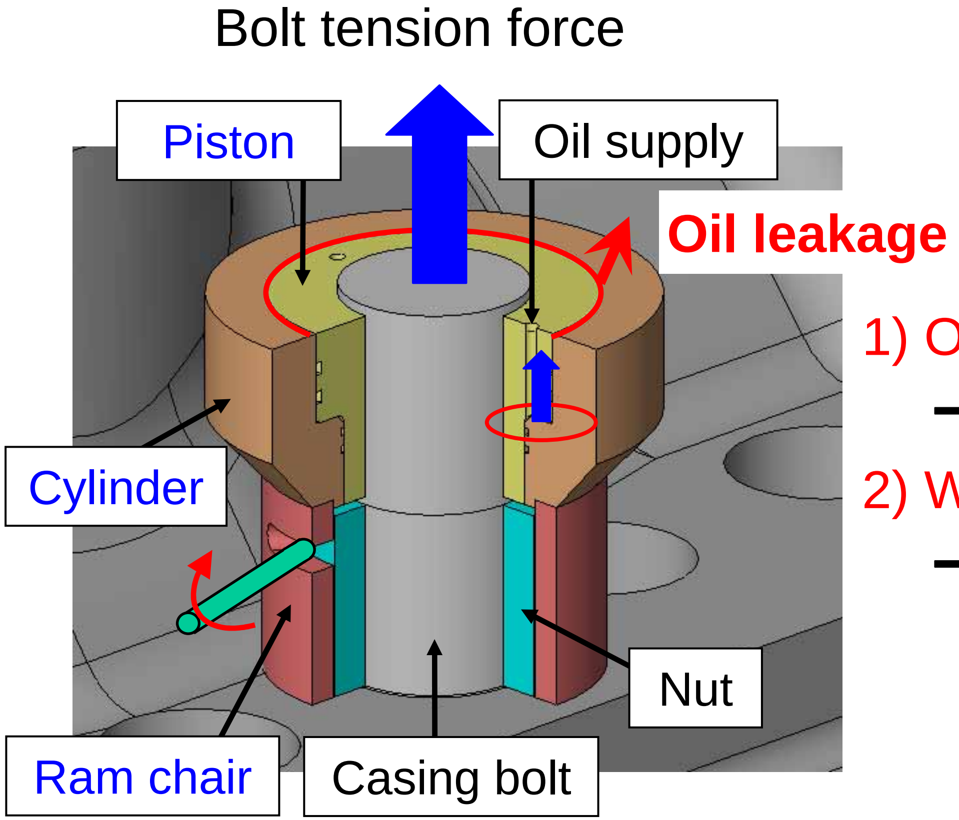
Step3. To tighten nut by bar under oil supply



Step4. To release oil supply, then, bolt to be tightened with remain extension

Conventional type of oil operated bolt tensioner

Technical issues



Experienced problem

1) Oil leakage from tensioner tool
→ High oil supply pressure

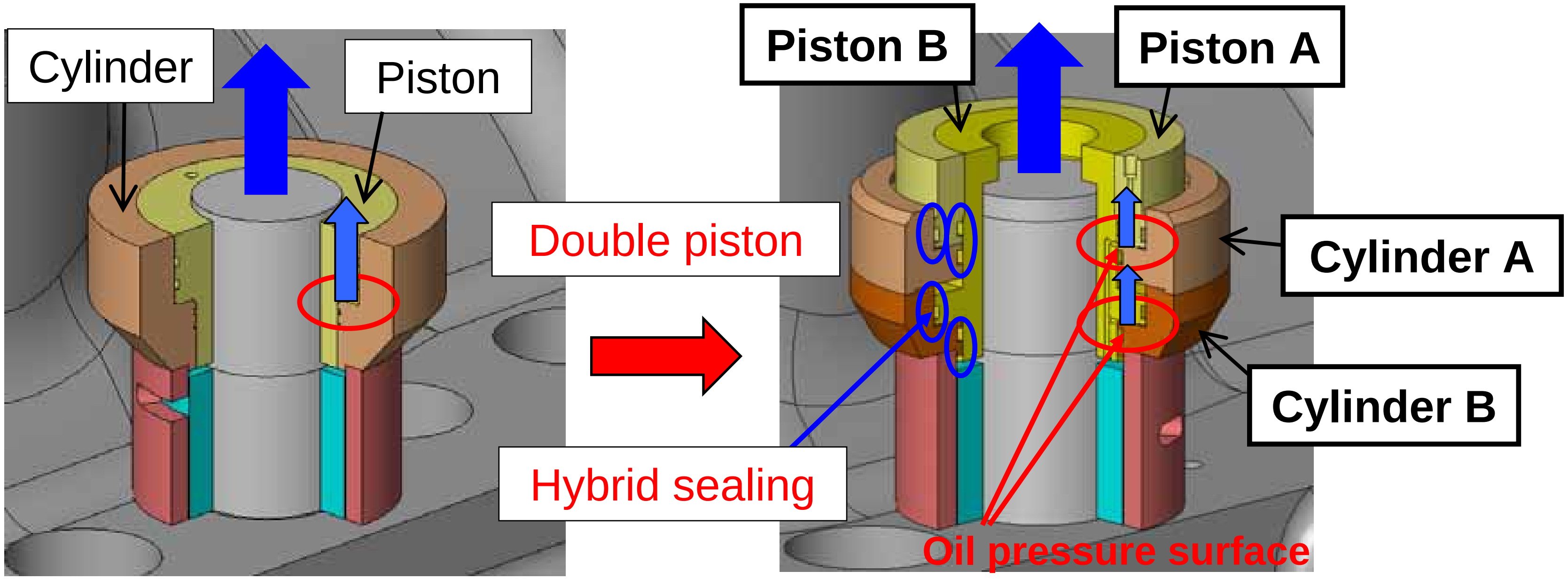
2) Water leakage at casing hydro test
→ Low tightening force
(Insufficient bolt tension force)

Necessity of Tensioner improvement

Advanced type of oil operated bolt tensioner(1/3)

Solution to technical issues of conventional oil operated

Advanced type to be developed by Double piston & Hybrid sealing structures



Conventional   Advanced

Features of Advanced type：

1)To prevent oil leakage

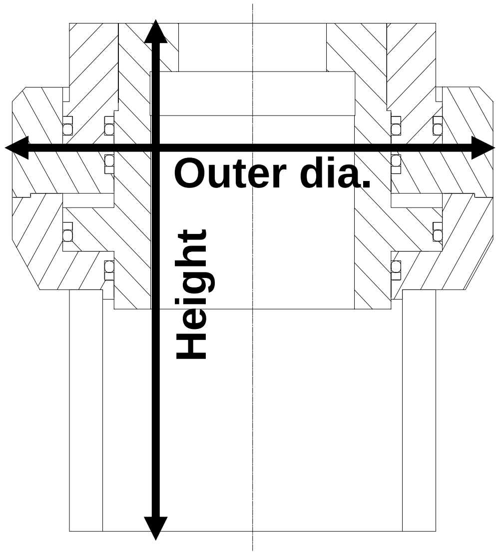
Hybrid sealing of back-up-ring and O-ring

2)To increase bolt tightening force

2.5 times up of oil pressure surface by double piston

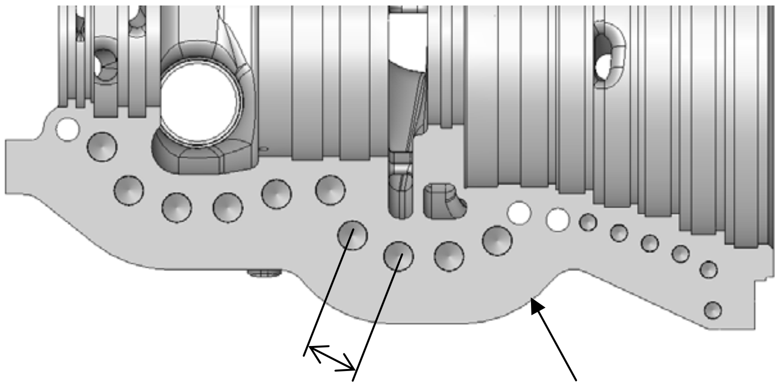
Advanced type of oil operated bolt tensioner(2/3)

Size comparison to conventional oil operated type



Size comparison Unit:mm

Bolt size	Outer dia. Conventional	Outer dia. Advanced	Height Conventional	Height Advanced
M80	Φ206	Φ203	165	212
M90	Φ222	Φ222	185	238
M110	Φ260	Φ260	225	265



Advanced type;

Compact design to keep almost same outer diameter

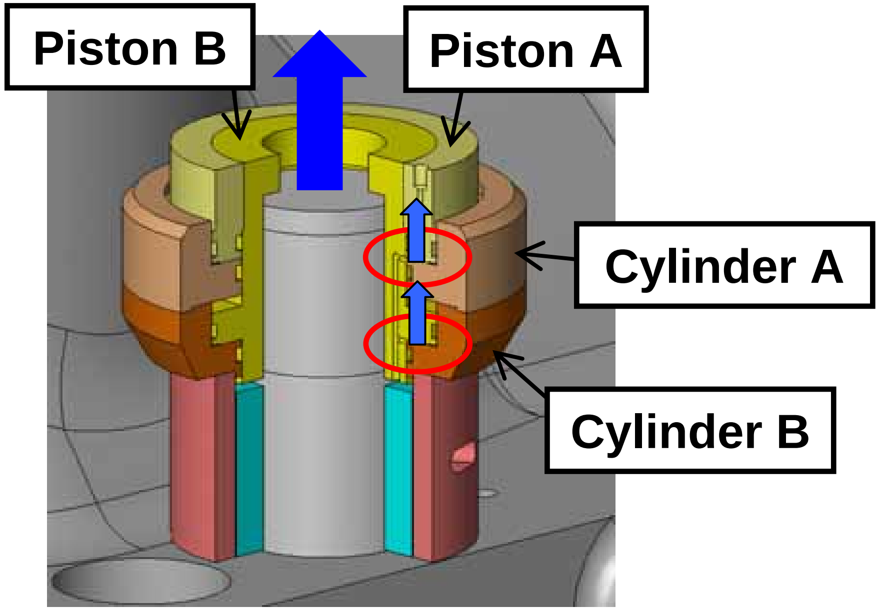
Effect;

Not necessary to extend casing bolt pitch

→ Keeping same casing seal performance

Advanced type of oil operated bolt tensioner(3/3)

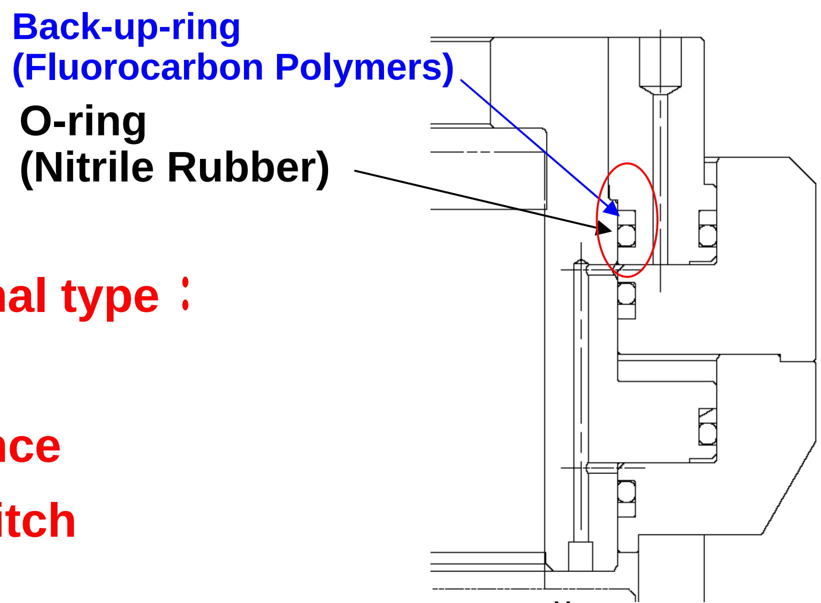
General specification



Advanced

General

1) Structure = Double piston type
2) Oil seal = Back-up ring and O-ring
3) Oil supply pressure
   = About Max. 150MPa
4) Maximum bolt tension force
   Up to 80% of bolt material yield force
5) Applicable bolt size
   M80、M90、M100、M110
   Note; M××, ××=Bolt diameter [mm]



Advantages compared to conventional type：

1)1.5 times up of bolt tension force

2)Enhancement of oil seal performance

3)Applicable to same bolt size and pitch

Reliability check of advanced type(1/4)

Reliability check list of oil operated bolt tensioner

Purpose	Check point	Evaluation	Criteria
Prevention of brittle fracture	**Impact value**	**Material test**	**Over 37.6J/cm^2 (Brittle fatigue limit)**
Prevention of tension failure	**Average stress**	**3D FEM analysis**	**Less than material yield stress**
Prevention of low cycle fatigue failure	**Peak stress**	**Langer's equation**	**Over 2,000 cycles*1**

***1: 2000 cycles > 30 casing bolts per turbine ✕2 numbers (Disassembly/Assembly)✕30 years**

Material test

Application of 17-4PH material = Higher tensile strength material

To prevent brittle fracture ➙ Impact value required to be over 37.6J/cm^2

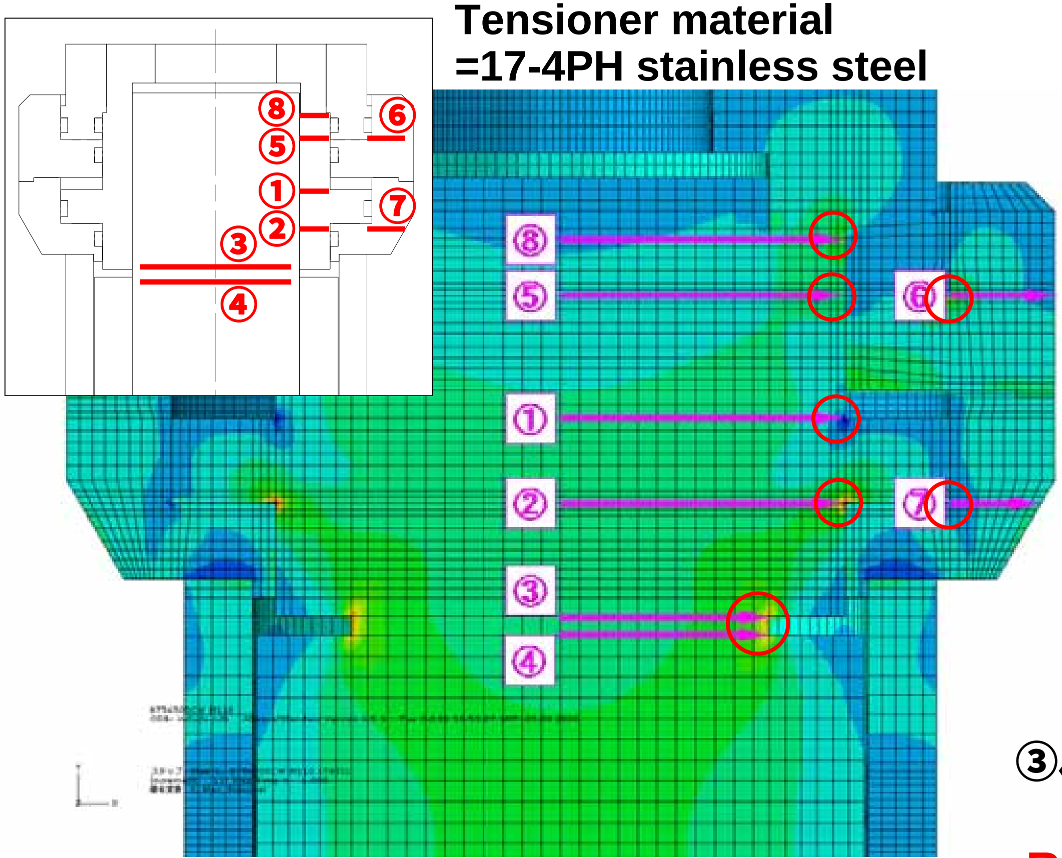
	Yield stress	Tensile stress	Elongation	Reduction area	Hardness (Brinell)	Impact (V-notch)
Specification	>1000MPa	>1070MPa	>12%	45%	>331HB	>37.6J/cm^2
Test piece No.1	1043	1081	20.4	64.0	341	110
Test piece No.2	1010	1140	18.8	46.9	375	113
Test piece No.3	1040	1086	21.6	60.5	341	128

Result; Enough satisfied with Spec. ➙Acceptable

Reliability check of advanced type(2/4)

Stress distribution under maximum oil pressurizing at 180MPa
(For advanced type, Bolt size M110)

Tensioner material =17-4PH stainless steel



Bolt material =13Cr stainless steel

Stress table

Cross section	Average stress MPa	Safety factor for material yield stress
①	4.8	21
②	70.9	1.4
③	49.5	1.6
④	50.1	1.5
⑤	12.2	4.3
⑥	26.0	3.9
⑦	5.6	18
⑧	42.1	2.4

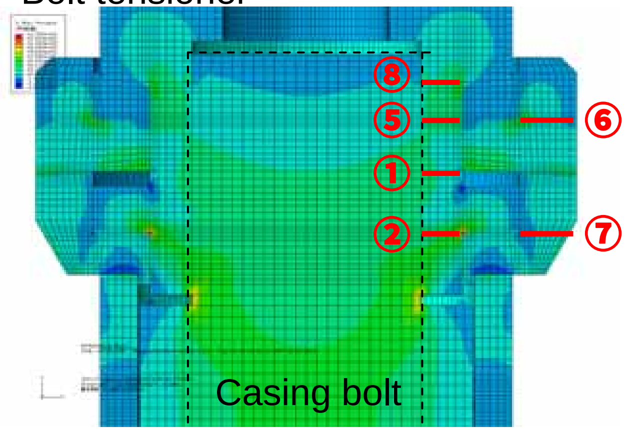
③、④= Casing bolt、Others = Bolt tensioner

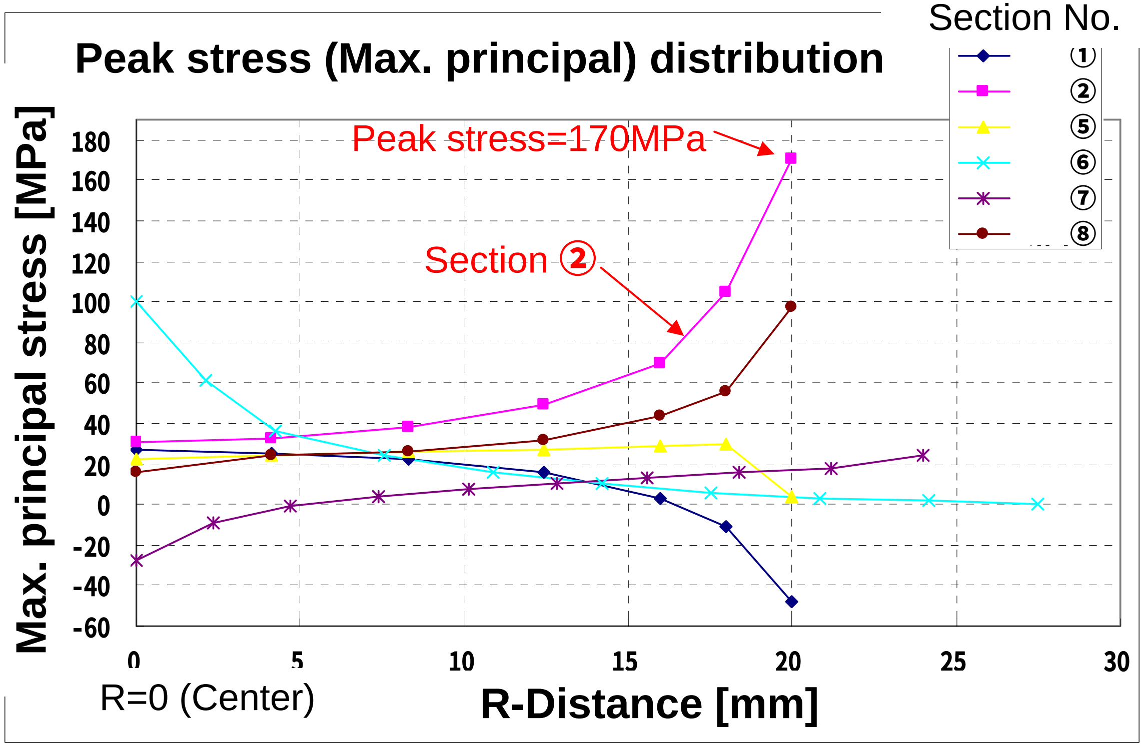
Result; Adequate safety margin

Reliability check of advanced type(3/4)

Evaluation of low-cycle-fatigue for bolt tensioner

Bolt tensioner





Langer-equation

$$\Delta\sigma_P = \frac{E}{2\sqrt{N}} \ln\left(\frac{1}{1-\phi}\right) + 2\Delta\sigma_W$$

$\Delta\sigma_P$: Allowable stress
E : Modulus of elasticity(=2.1×10^4)
N : Allowable repeat cycle(=2000)
ϕ : Reduction of area(=0.45)
$\Delta\sigma_W$: Endurance limit(=49)

Result;
Allowable stress ＝240MPa ＞ 170MPa(Peak)
Adequate safety margin for no low-cycle-fatigue failure in 2000 cycles

Reliability check of advanced type(4/4)

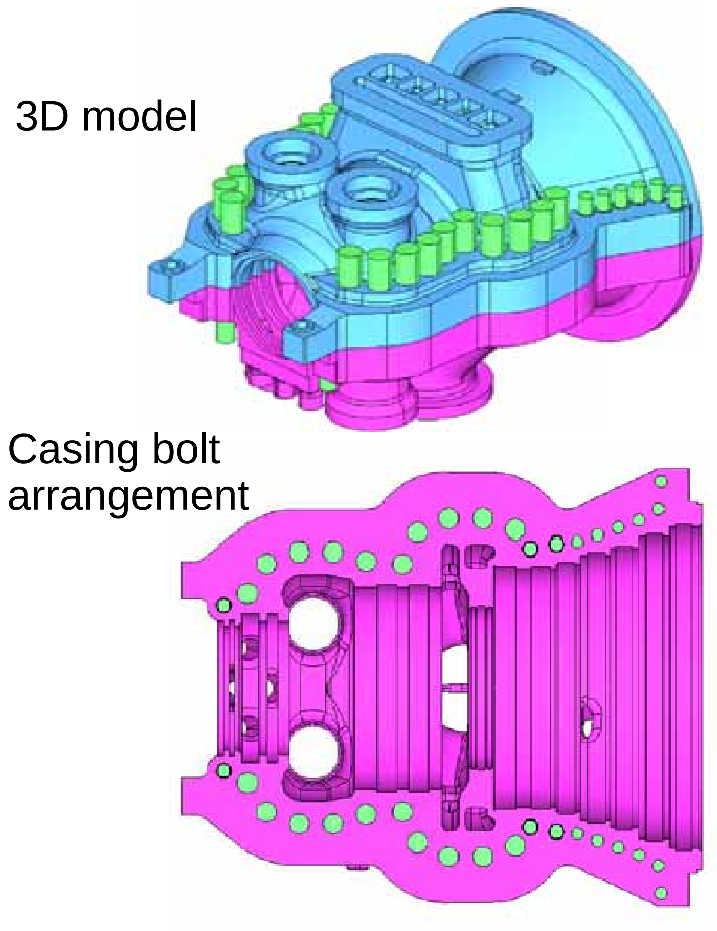
Summary result of reliability check

Purpose	Criteria	Result
Prevention of tension failure	**Less than material yield stress**	**Highest average stress to be Min. Safety 1.4 for allowance**
Prevention of low cycle fatigue failure	**Over 2,000 cycles**	**Peak stress to be min. safety 1.4 for allowance**
Prevention of brittle fracture	**Over 37.6J/cm^2 (Brittle fatigue limit)**	**More than 100J/cm^2**

Advance type;
1) More safety operation of bolt tensioner
2) Much longer life time to use in over 2000 cycles
3) Tensioner material to be more toughness without brittle fracture

Application to large-sized steam turbine(1/4)

Seal analysis of large-sized steam turbine under hydro test



Analysis 3D model of turbine casing

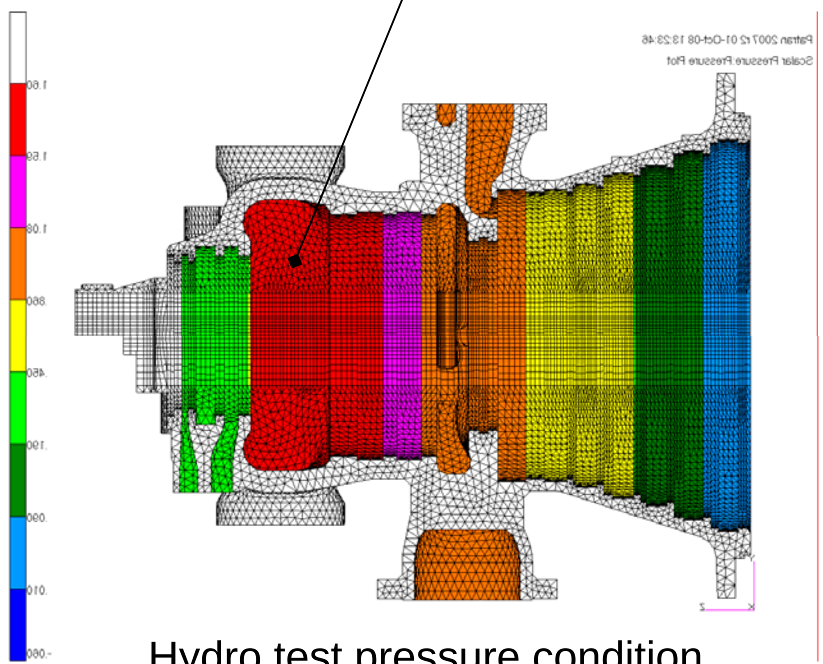
<u>Mechanical design of HP section turbine casing</u>

Pressure=1830psig (126barg)

Temperature=894degF(479degC)

(Turbine power =Max.86MW、Inlet flow =Max.650Ton/Hr)

Hydro pressure = Max.2280psig(157barg) in casing integrity test



Hydro test pressure condition

Application to large-sized steam turbine(2/4)

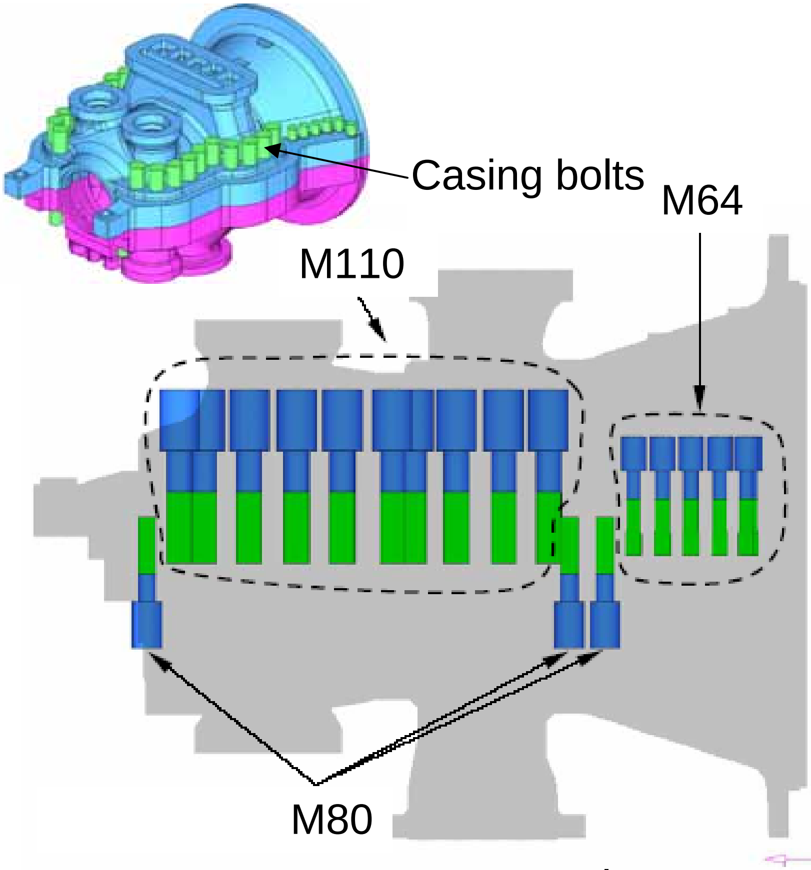
Seal analysis of large-sized steam turbine under hydro test

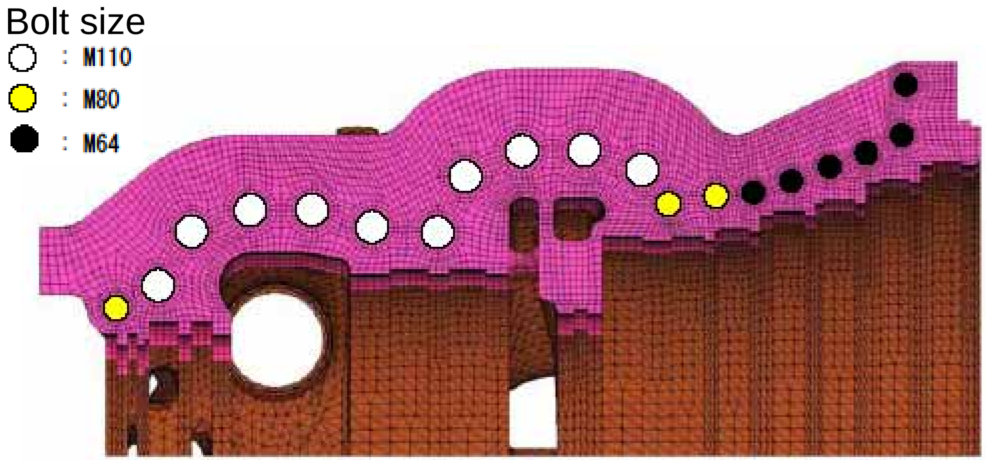
Comparison of bolt tightening force
(Conventional & Advanced bolt tensioner)

Bolt tightening force(Stress)	Conventional	Advanced
M110	2.8×10^{6} N (340MPa)	→ 3.8×10^{6} N (480MPa)
M80	1.3×10^{6} N (310MPa)	→ 1.8×10^{6} N (440MPa)

(M64=Tightening by Power wrench)

1.4 times up of tightening force by advanced type



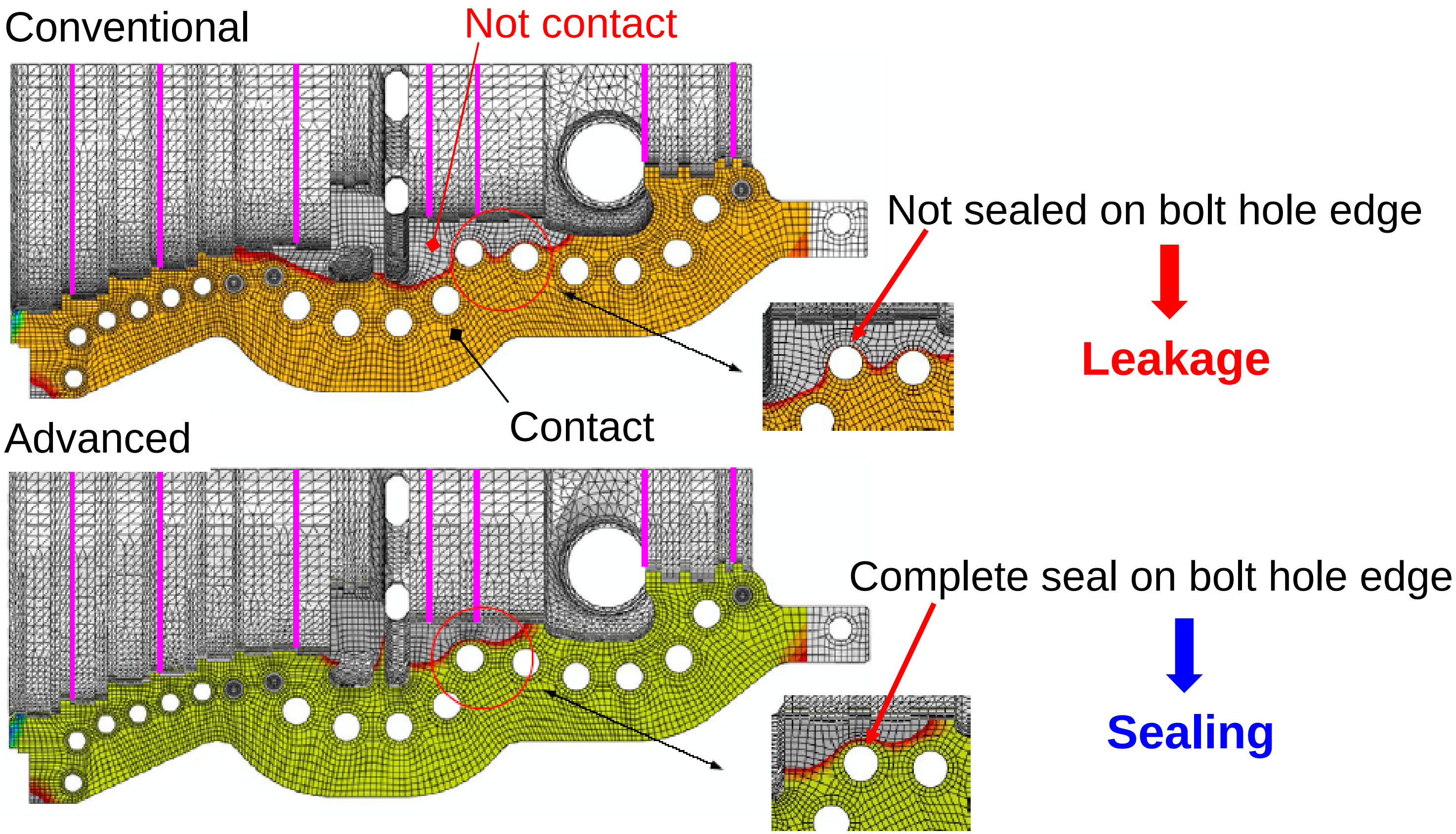


Bolt arrangement and tightening force

Application to large-sized steam turbine(3/4)

Seal analysis of large-sized steam turbine under hydro test

Analysis result



Contact condition of horizontal casing surface in hydro casing integrity test

Application to large-sized steam turbine(4/4)

Hydro test of turbine casing

Test result of casing integrity and joint leakage;

Neither leaks nor seepage through casing is observed

Successful hydro test of turbine casing by advanced bolt tensioner

Conclusions

Advanced type of oil operated bolt tensioner is successfully designed to enhance the reliability for large-sized steam turbine with higher inlet steam pressure as follows;

a) **Compared to conventional type, the following items are improved.**

   a-1)Achievement of 1.5 times up of bolt tension force by double piston

   a-2)Enhancement of oil seal performance by hybrid sealing

   a-3)Applicable to same bolt pitch by compact design

b) **Bolt tightening work time can be saved with more safety compared to bolt heater type thanks to no heating time and operation.**

c) **By 3D FEM analysis and material test, adequate strength against tension, fatigue, brittle fracture are verified. Also, life time can be obtained in more than 2000 cycles. Finally, the advanced type can achieve successful hydro test of turbine casing with no leakage or seepage.**

d) **To get a reliability increase of turbine casing seal performance in the future, minimization of casing bolt pitch is necessary with modification structure to be studied in next technical issue.**