구두발표[발전설비 운영 및 유지정비]

노후화된 증기터빈의 현대적 블레이드 기술을 반영한 개조방안

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목 차

1. 연구 개요

❖ 연구 배경

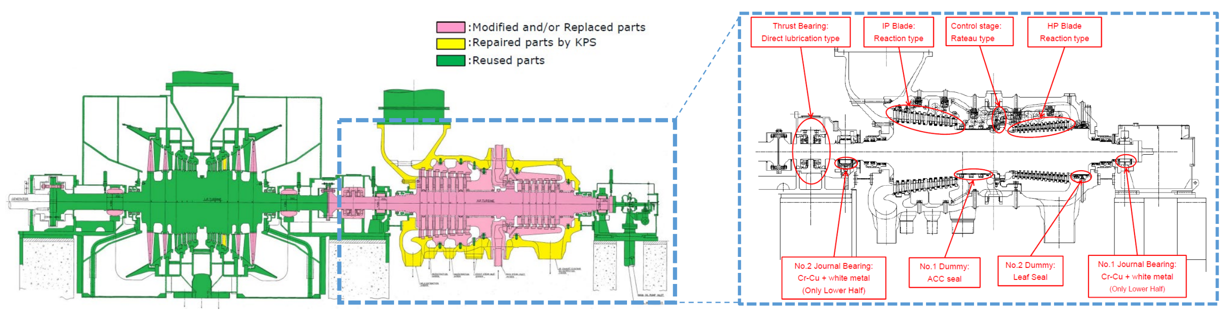
◆ 90년대 노후화 증기터빈의 Retrofit을 통해 성능을 향상시키는 프로젝트를 진행하였으며, 성능 향상치 확인 및 이에 대한 검증을 수행함.

❖ 연구 내용

추진계획	추진실적	추진 성과
1. 성능개선 방안 검토 - Reaction 및 단수 별 성능향상 방안 검토 - 증기누설량에 따른 성능변화량 검토 **2. 검증방안 검토** - ASME PTC Code Test에 따른 검증 - AxSTREAM을 활용한 성능모델 Simulation 결과검증	**1. 개선된 설계기법을 통한 Retrofit 추진** - High Reaction 블레이드의 적용 - 기존 Conventional Blade 대신 Twisted Blade의 적용 - 개선된 Blade Cover 기술의 적용 - Advanced Seal의 적용 **2. 성능시험과 성능모델 Simulation 결과 교차 검증**	Retrofit 전, 후 약 2~3%의 성능향상이 가능함을 성능시험과 성능 시뮬레이션을 통하여 확인함.

❖ Retrofit 수행범위

- Control Stage
- HP/IP Blade
- Shaft End Packing
- Thrust Bearing



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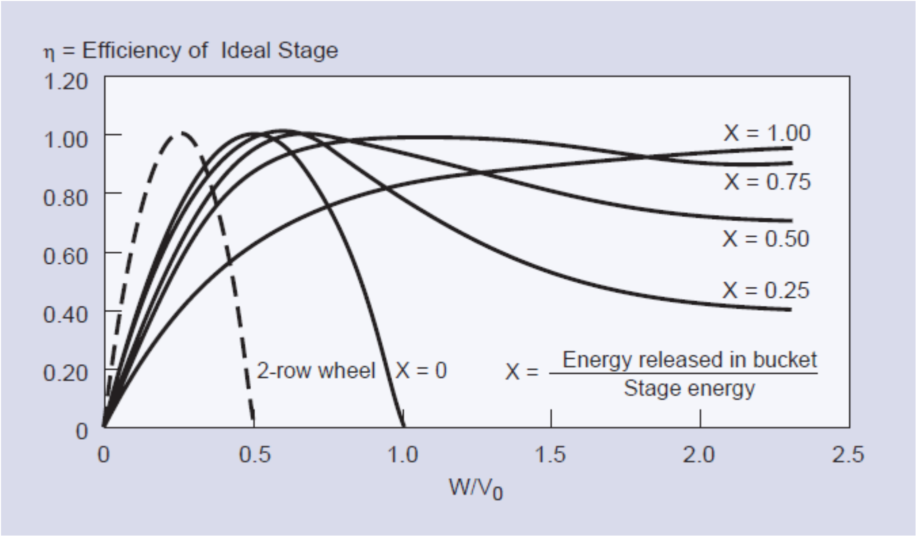
2. 성능개선 기술

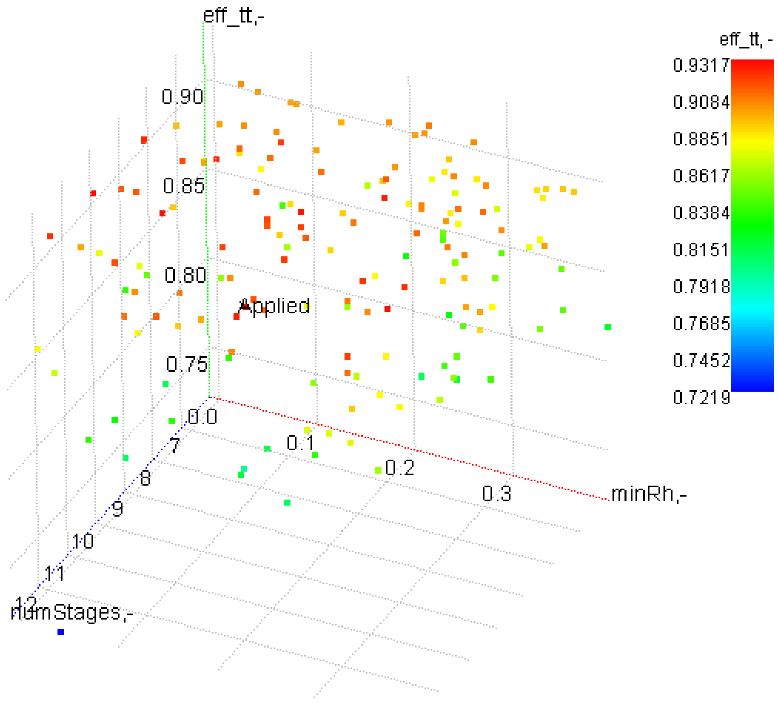
❖ Reaction 및 단수 별 성능 영향성 검토

◆ 증기터빈의 단 별 성능은 그 단에서의 축방향 속도와 회전방향 속도의 비(Velocity Ratio, W/Vo)와 상관관계가 있으며, 축방향 속도는 해당 단에서의 압력강하 값으로 결정되고, 회전방향 속도는 해당 단에서의 Diameter와 밀접한 관련이 있음. 일정 범위 내에서의 변수의 조합으로 다양한 해를 구하고 이를 분석하여 최적의 효율이 도출되는 설계 Point를 추적함.



<Efficiency of an ideal stage as a function of velocity ratio for various values of bucket reaction>

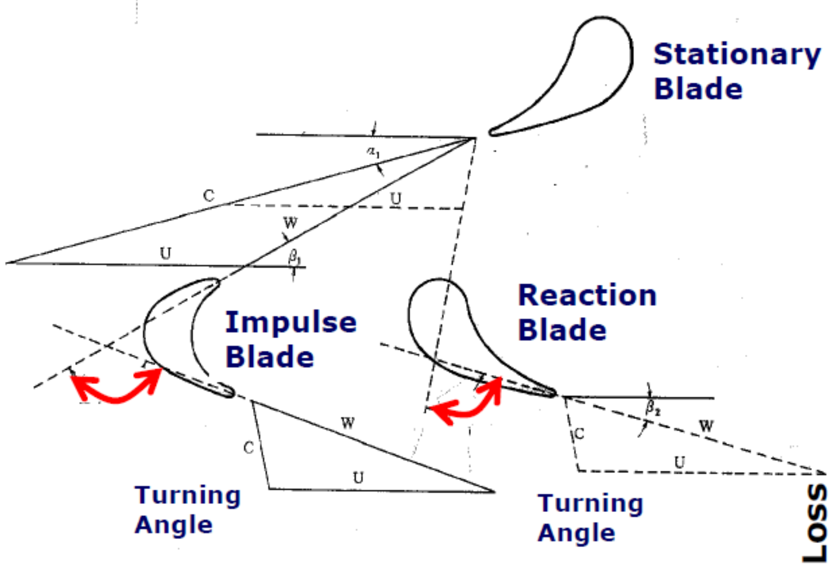
☞ Source :Steam turbine and their cycle, J.K. Salisbury, 1950

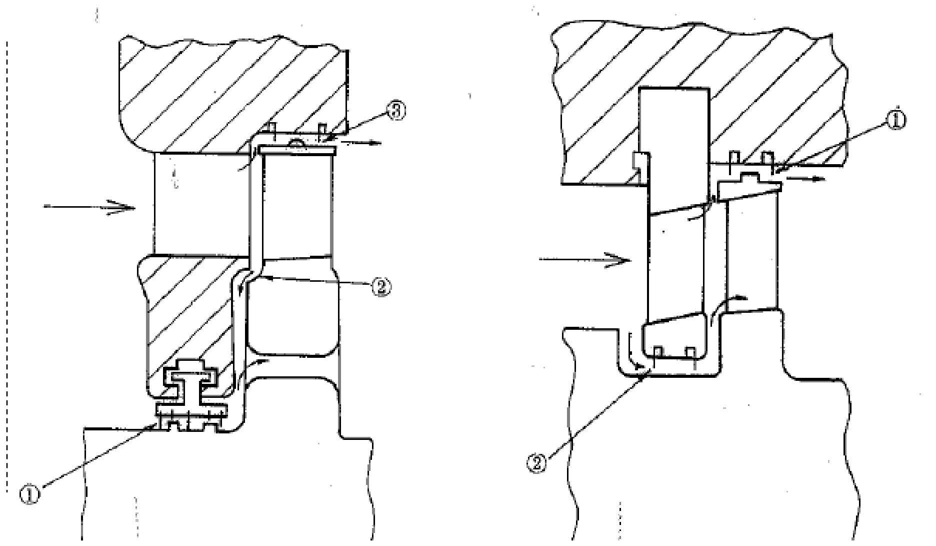


2. 성능개선 기술

❖ Reaction 및 단수 별 성능 영향성 검토

◆ Reaction Blade는 Impulse Blade에 비하여 Blade의 Turning Angle이 작고 Rotating Blade의 입구 증기속도가 작아 Loss값을 줄일 수 있음. 다만 Rotating Blade의 입출구 압력차이가 크기 때문에 누설 손실이 상대적으로 크므로 효과적인 Sealing 이 필요함.





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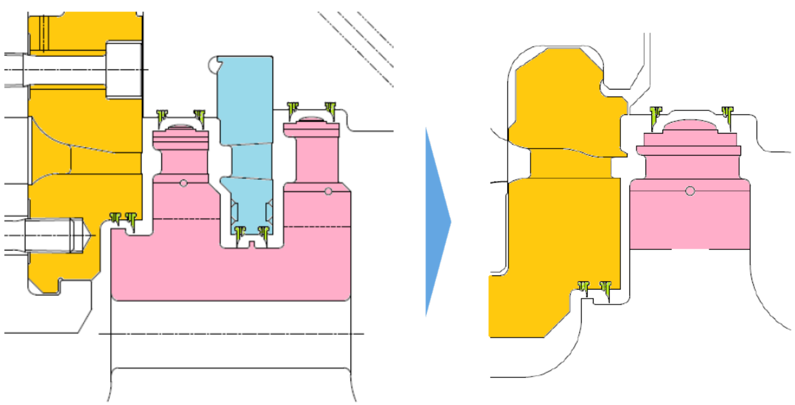
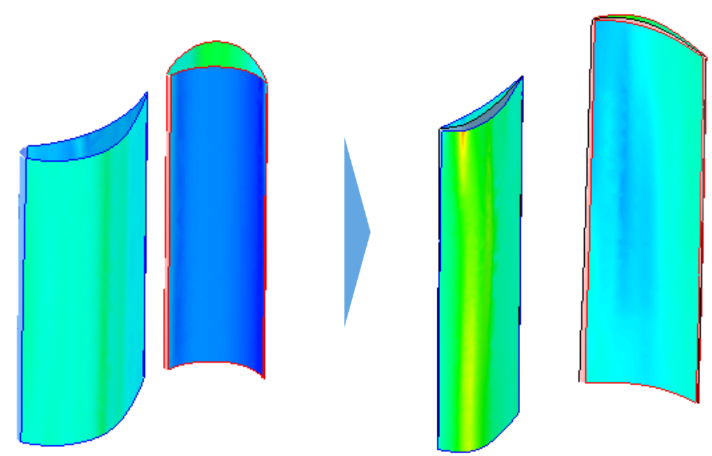
❖ Reaction 상승에 따른 3D Blade 설계

◆ Reaction이 높은 Blade 적용을 위하여 3D 설계의 개념이 들어가며, 따라서 기존의 Conventional Blade가 아닌 Twisted Blade가 적용됨.

Item	Existing	After Retrofit
Control Stage	Curtis	Rateau
HP, IP Blade	Impulse HP : 6 stages, IP : 7 stages	Reaction HP : 14 stages, IP : 12stages
Thrust Bearing	Oil Bath lubrication thrust bearing	Direct lubrication thrust bearing



Curtis(Existing)　　Rateau



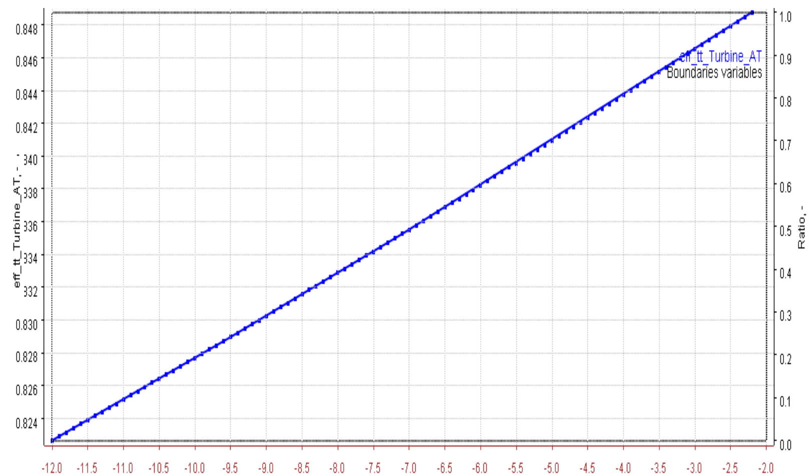
Impulse Blade　　Reaction Blade

❖ 증기누설 저감을 위한 Advanced Seal 적용

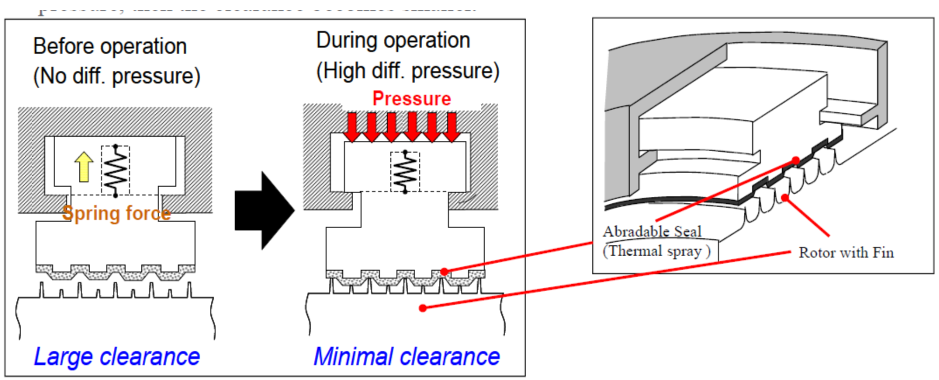
◆ Reaction 증가에 따라 누설에 의한 성능 손실치가 증가하므로 누설 저감을 위한 Advanced Seal 적용을 고려하였음.

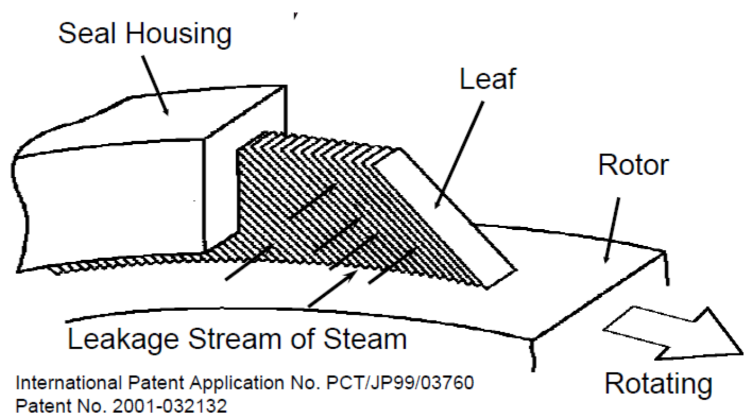
❖ **Example) HP internal efficiency increase according to decreasing N2 leakage flow.**

[HP Efficiency]



[N2 leakage flow]





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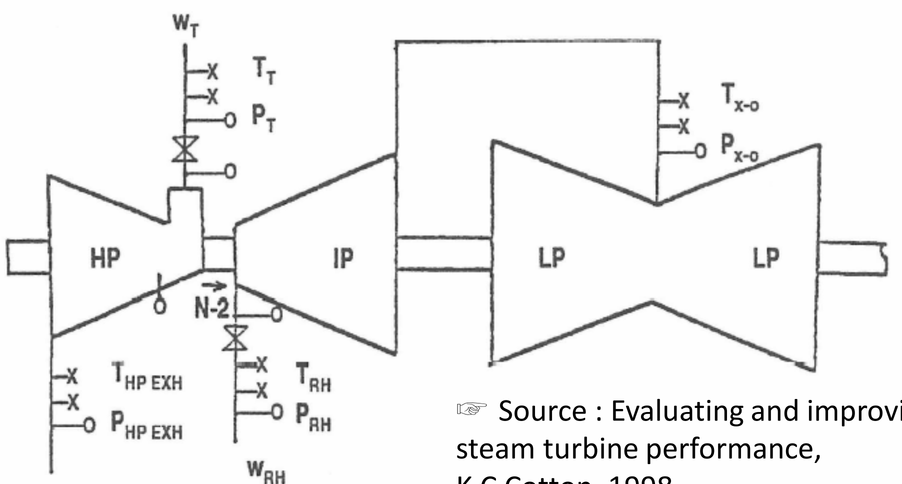
3. 검증 및 결과

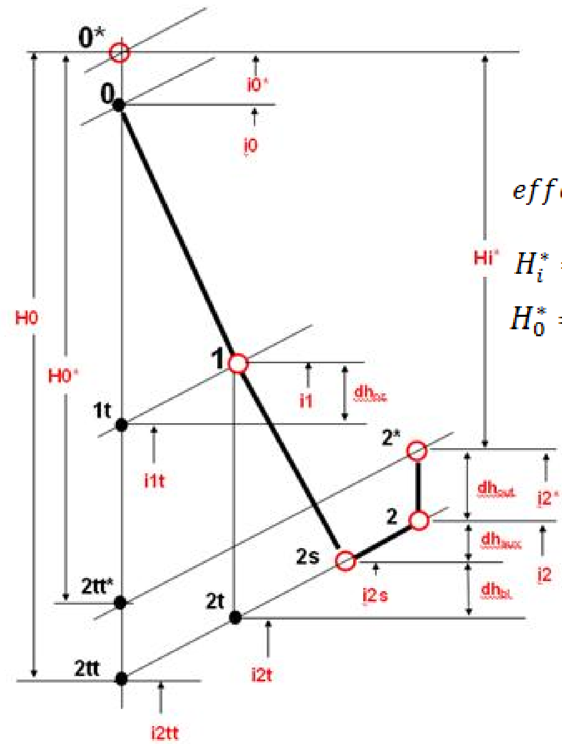
❖ Performance Test를 통한 검증

◆ ASME PTC-6 Code에 따른 성능 검증 (Alternative Test)

- 고압터빈과 중압터빈의 경우 성능 측정을 위하여 Enthalpy Drop Test 기법을 적용



☞ Source : Evaluating and improving steam turbine performance, K.C.Cotton, 1998



$$eff\,d_{tt} = \frac{H_i^*}{H_0^*}$$

$$H_i^* = i_0^* - i_2^*$$

$$H_0^* = i_0^* - i_{2tt}^*$$

❖ **HP Turbine after retrofit**

- ◆ P_T:128.16kg/cm2, T_T:540.02℃, I_T:823.96kcal/kg
- ◆ $P_{HP\ EXH}$:26.22kg/cm2, $T_{HP\ EXH}$:322.36℃, $I_{HP\ EXH}$:731.14kcal/kg

❖ **IP Turbine after retrofit**

- ◆ P_{RH}:24.56kg/cm2, T_{RH}:540.33℃, I_{RH}:848.73kcal/kg
- ◆ $P_{IP\ EXH}$:2.85kg/cm2, $T_{IP\ EXH}$:244.69℃, $I_{IP\ EXH}$:706.47kcal/kg
- ◆ X-Over 측정 Point 부재로 IP Exhaust Data로 평가함.

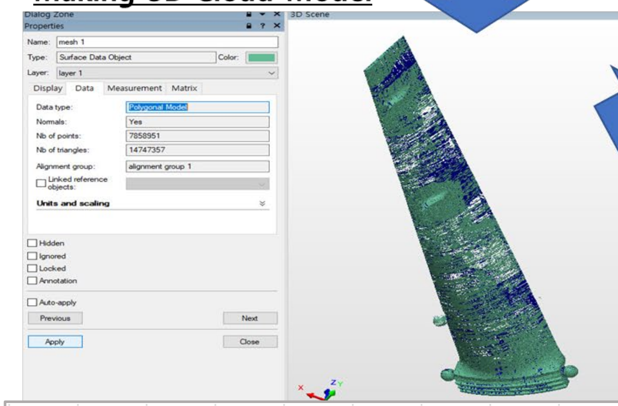
❖ **Test Result**

- ◆ HP Section efficiency : 84.24%
- ◆ IP Section efficiency : 94.02%

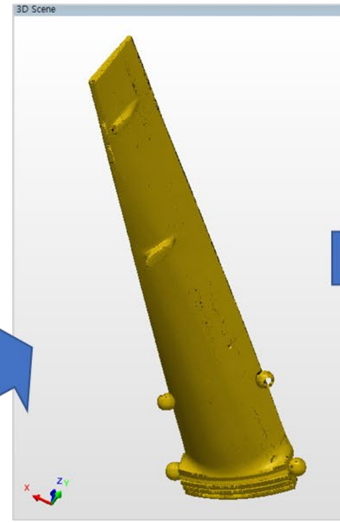
3. 검증 및 결과

❖ 성능모델 시뮬레이션을 통한 검증

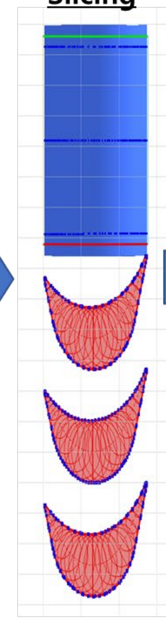
Making 3D Cloud Model



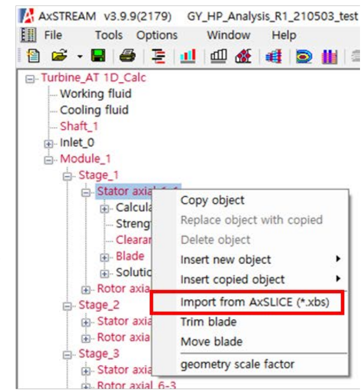
Transfer to polygonal model

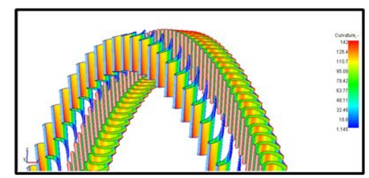


Slicing

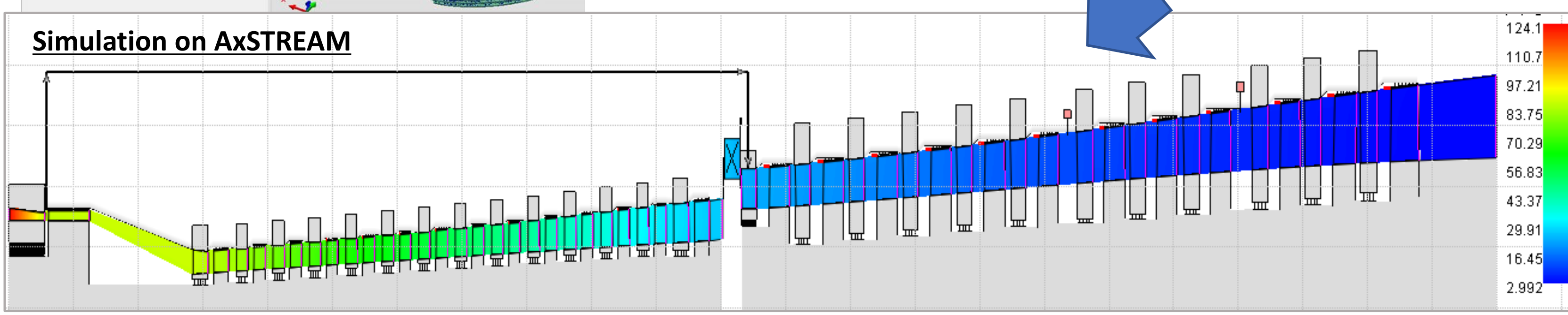


Input to AxSTREAM



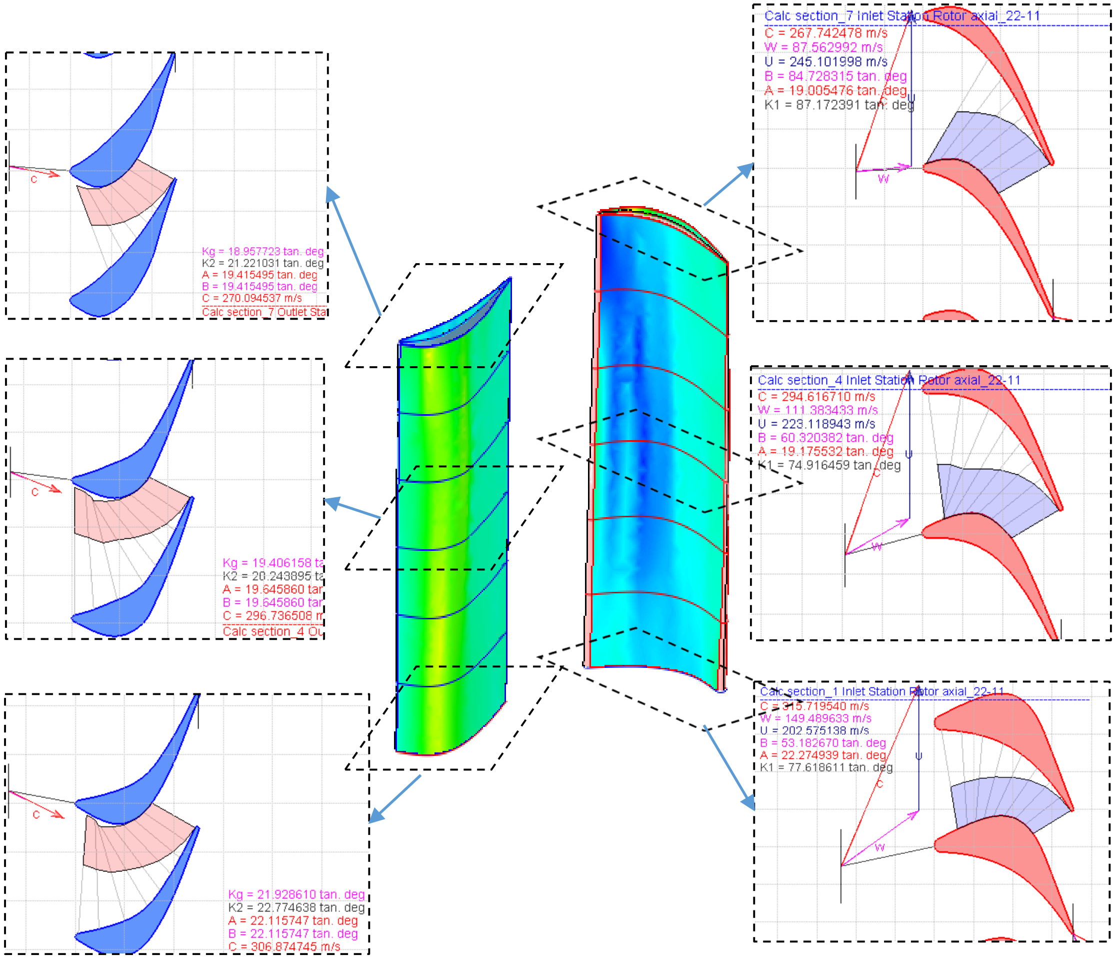


Simulation on AxSTREAM



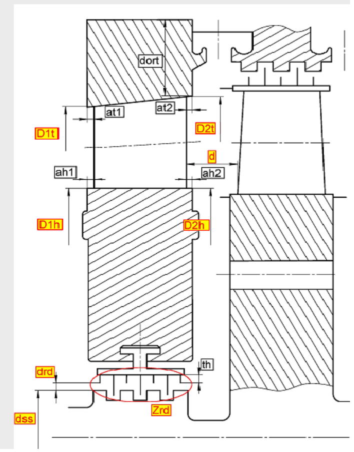
3. 검증 및 결과

❖ Performance Modeling



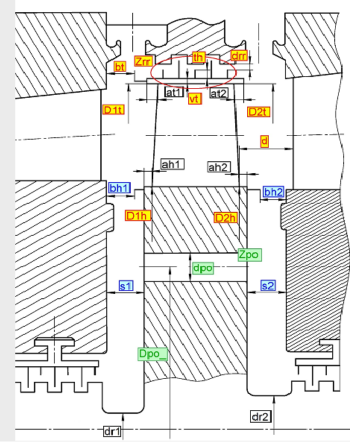
Stator Clearances Setup

	Property	Unit	Value
sealTy	seal type	-	High-Low
statorT	stator type	-	Active diaphrag
mandatory data (yellow)			
z	number of blades	-	104
d	axial hub clearance d/s blade	mm	18.963882
drd	stator diaphragm radial clearance	mm	0.150000
Zrd	stator diaphragm seal teeth number	-	100
dss	seal diameter	mm	870.000000
D1h	hub diameter at inlet	mm	927.154426
D2h	hub diameter at outlet	mm	930.329750
D1t	tip diameter at inlet	mm	1060.224063
D2t	tip diameter at outlet	mm	1055.061881
optional for flow path meridional view detailing (white)			
at1	tip closed axial gap u/s blade	mm	0.000000
at2	tip closed axial gap d/s blade	mm	0.000000
dort	diaphragm outer ring thickness	mm	29.164875
th	seal tooth height	mm	9.300000



Rotor Clearances Setup

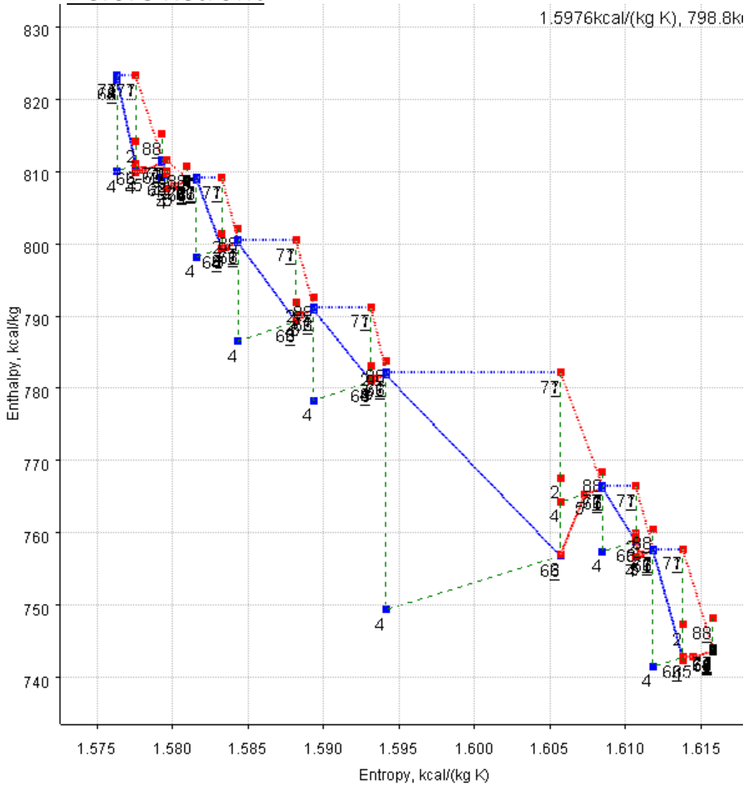
	Property	Unit	Value
sealTy	seal type	-	Straight-Smooth
shroud	shroud type	-	shrouded with r
mandatory data (yellow)			
z	number of blades	-	95
d	axial hub clearance d/s blade	mm	9.193927
bt	tip open gap u/s blade	mm	11.000000
drr	rotor shroud radial clearance	mm	1.000000
Zrr	rotor shroud seal teeth number	-	6
th	seal tooth height	mm	1.000000
vt	shroud thickness	mm	2.000000
D1h	hub diameter at inlet	mm	932.728450
D2h	hub diameter at outlet	mm	939.061692
D1t	tip diameter at inlet	mm	1060.657813
D2t	tip diameter at outlet	mm	1065.011107
mandatory for leakage balance (blue)			
bh1	hub open gap u/s blade	mm	0.000000
bh2	hub open gap d/s blade	mm	0.000000
s1	disc cavity width u/s blade	mm	0.000000
s2	disc cavity width d/s blade	mm	0.000000
optional for leakage balance (green)			
Dpo_	diameter of balance holes location	mm	0.000000
dpo	balance hole diameter	mm	0.000000
Zpo	balance holes number	-	0
optional for flow path meridional view detailing (white)			
at1	tip closed axial gap u/s blade	mm	0.000000
at2	tip closed axial gap d/s blade	mm	0.000000
dr1	inlet bushing diameter	mm	868.000000
dr2	outlet bushing diameter	mm	808.000000



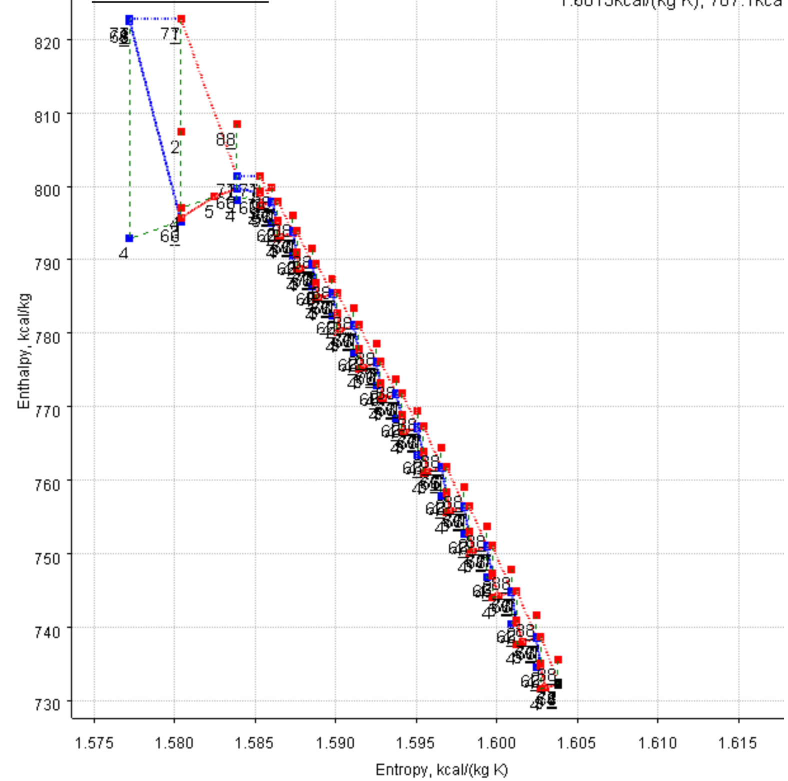
3. 검증 및 결과

❖ 검증 결과 (HP Section)

Before Retrofit



After Retrofit



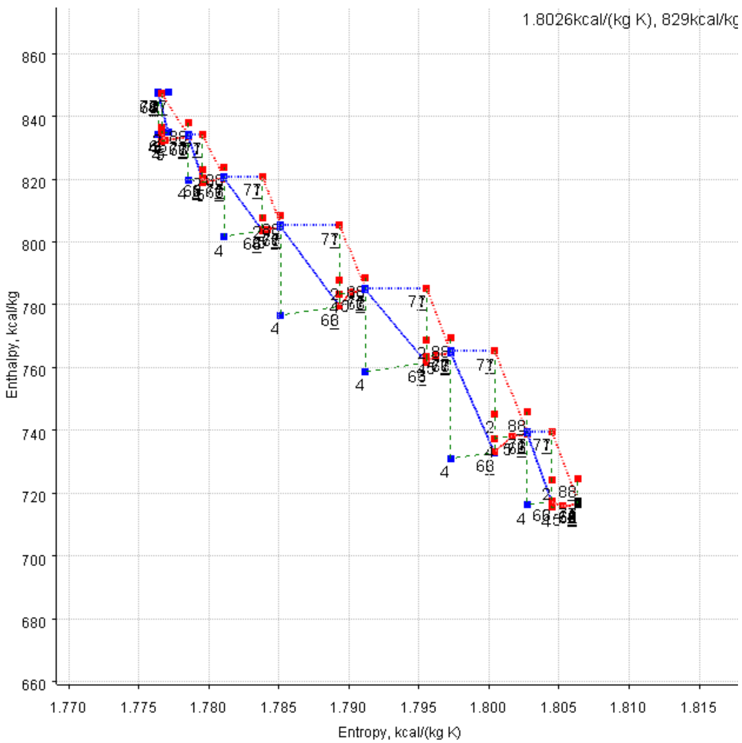
HP Turbine (Before Retrofit)	Design HBD	Performance Test	AxSTREAM Simulation
Section Efficiency [%]	82.54%	75.37%	80.15%

HP Turbine (After Retrofit)	Design HBD	Performance Test	AxSTREAM Simulation
Section Efficiency [%]	83.62%	84.24%	85.09%

3. 검증 및 결과

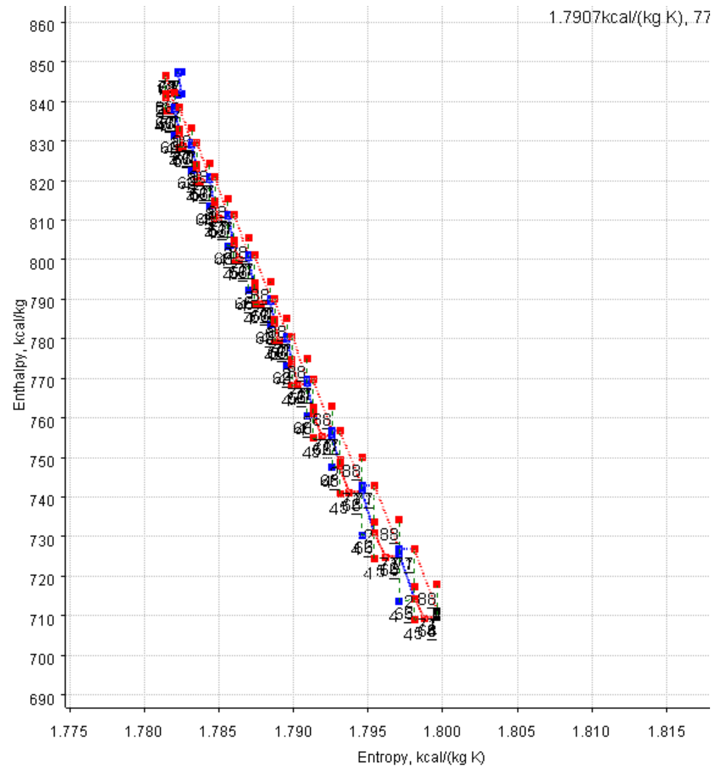
❖ 검증 결과 (IP Section)

Before Retrofit



IP Turbine (Before Retrofit)	Design HBD	Performance Test	AxSTREAM Simulation
Section Efficiency [%]	89.82%	89.55%	90.39%

After Retrofit

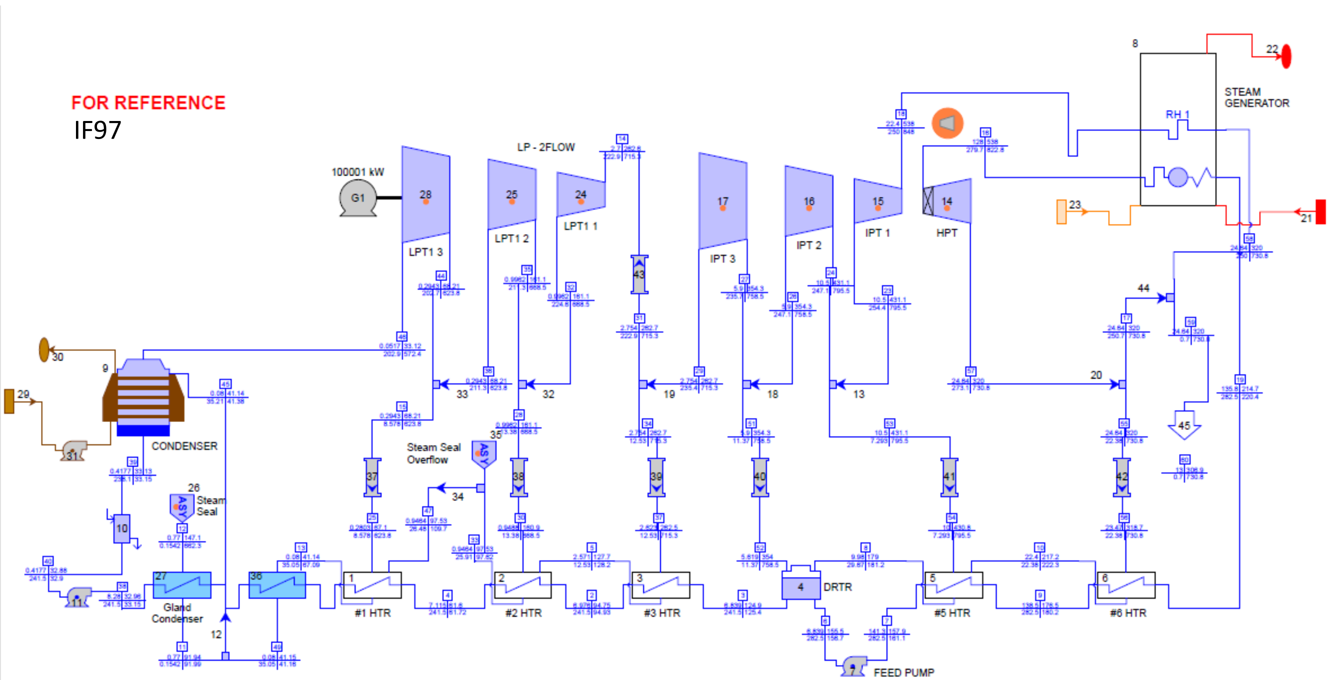


IP Turbine (After Retrofit)	Design HBD	Performance Test	AxSTREAM Simulation
Section Efficiency [%]	95.18%	94.02%	93.63%

3. 검증 및 결과

❖ 검증 결과 (Performance Test_Cycle)

◆ 검증결과 노후화된 플랜트 대비 약 2~3%의 사이클 효율 향상이 있는 것으로 평가되었으며, 해당 효율 향상치는 노후화로 인한 Degradation 회복값과 설계 변경에 따른 성능 향상치가 복합적으로 반영되어 나타난 결과임.



GHR : Turbine generator gross heat rate
F1 : Main steam flow
F37 : Final feed water flow
F3 : Hot reheat flow
F53 : Cold reheat flow before reheater spray
F38 : Process steam flow
F54 : Boiler auxiliary steam flow
F10 : Condenser make-up water flow
F52 : Reheater spray flow

$$GHR = \frac{F1 \cdot H1 - F37 \cdot H37 + F3 \cdot H3 - F53 \cdot H2 - F38 \cdot H38 - F54 \cdot H2 + F10 \cdot H10 - F52 \cdot H52}{E1}$$

4. 결론

❖ 성능시험 결과 성능개선 전,후 약 2~3%의 Cycle 성능이 향상되는 것을 확인하였으며, 성능 Simulation을 통한 교차 검증 결과 1%이내에서 동일한 결과가 도출됨을 확인함.

◆ Retrofit을 통한 성능 향상치

	SECTION			CYCLE
	HP SECTION	IP SECTION	LP SECTION	
Retrofit 전	75.37 %	89.55%	Retrofit 대상제외	XX.X%
Retrofit 후	84.24 %	94.02%		XX.X%
향상치	+ 8.87 %	+4.47%		About 2~3%

◆ 교차 검증 결과 (Retrofit 후 기준)

	SECTION		
	HP SECTION	IP SECTION	LP SECTION
PERFORMANCE TEST	84.24 %	94.02%	Retrofit 대상제외
PERFORMANCE SIMULATION	85.09 %	93.63%	
DEVIATION	+0.85 %	-0.39%	

감사합니다.

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