Development of a Small-Scale Supercritical CO2 Turbine Power System

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Objective

- **Develop a** "10kw SCO2 Turbine Power System" (**2016/ 01/ 01~2018/ 12/ 31**) ，including：
- 1. Indirect Heat Source SCO2 System

  for Waste Heat, Geothermal Source… ；
- 2. Direct Heating SCO2 System

  Oxyfuel Combustor Design & Preliminary test

*Joined with some heavy industries and Universities

Industry Consortium

China Steel

- Onsite available waste heat
- Agree to provide heat source to test
- Matching fund of 7.5%

CSIST

- Provide Turbomachinery assistance

MIRDC

- SCO2 Fluid Properties and System Monitoring

Taiwan Waste Heat Potential

工業技術研究院
Industrial Technology Research Institute

臺灣廢熱節能減碳潛力

項目	數量	單位	備註
全國能源耗量	111.5	百萬公秉油當量	
工業部門能源耗量	42.55	百萬公秉油當量	38.16%全國能源耗量
工業部門廢熱排放量	21.27	百萬公秉油當量	50%工業部門能源耗量 (以最高占比為例)
低溫廢熱量 [< 230°C]	14.89	百萬公秉油當量	70%工業部門廢熱排放量
	22.18	GWth	以 80%容量因素計算
可發電量	0.44	GWe	以取熱率 40%, 裝置率 60%, 發電效率 8% 計算
中溫廢熱量 [230°C~650°C]	6.38	百萬公秉油當量	30%工業部門廢熱排放量
	9.51	GWth	以 80%容量因素計算
可發電量	0.29	GWe	以取熱率 55%, 裝置率 55%, 發電效率 10% 計算
ORC 總建置容量	0.73	GWe	包括：煙氣、廢蒸汽、製程冷凝熱水等
年發電量	5116	百萬度/年	以 80%容量因素計算
節能	1.275	百萬公秉油當量	以 0.2484L 油當量/kWh 計算
減碳量	3.2	MtCO2/年	以 0.623kg/kWh 計算

- ORC發電機組特色
  - 熱回收應用範圍廣泛
    - 製程廢熱
    - 廢蒸汽
    - 廢熱液
    - 煙道排氣
  - 免燃料費
  - 高可靠度
  - 低運維成本
  - 壽命期長
  - 節能減碳效益
  - 低溫廢熱高效回收發電
  - 降低後端設備熱負載

Waste Heat in Taiwan

- High temperature waste heat recovery from cogeneration and boiler
- < 250°C waste heat recovery using ORC (μ=10~15%)
- Current heat recovery suffers from **cost** , **footprint** , **efficiency**

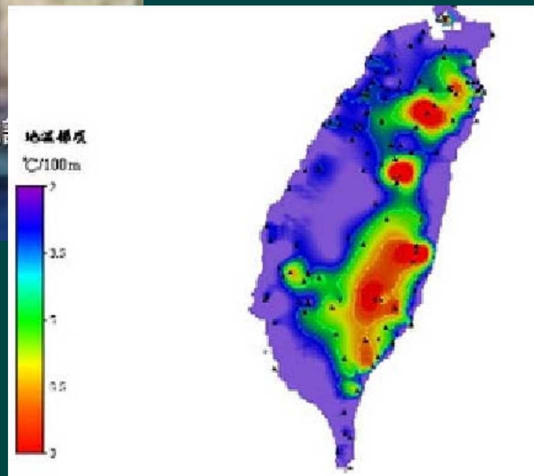
Taiwan Geothermal Resources

台灣地熱發電資源

清水、土場等宜蘭地區	11688MW
南投廬山	3592MW
花蓮瑞穗	3557MW
台東金峰、金崙	3139MW
高雄寶來	2851MW
台東霧鹿	2515MW
嘉南中崙、關子嶺	2423MW
大屯山火山群	2075MW
總計	31840MW

來源:工研院EGS地熱區潛能

畫面翻攝自網路



Main Tasks

a. Design and Analysis of the SCO2 System Thermal Cycle；
b. Design and Fabricate of the Turbine & Compressor Subsystem;
c. Alternator (ISG) Design and Assembly;
d. 10 Kw SCO2 Power System Integration & Test
e. Oxyfuel Combustor Simulation, Design and Fabricate

10 Kw SCO2 System Specifications

- a. Turbine Inlet Temp.~300 C, Pressure~14.1 Mpa.
- Turbine Outlet Temp. ~250 C, Pressure ~8.5 Mpa.
- Compressor Inlet Temp.~32 C, Pressure~7.8 Mpa.
- Compressor outlet Temp.~50 C, pressure~14.5 Mpa.
- Heat Exechanger Temp. difference(△T =50 C~150C),
- Pressure Loss each Step (△P~0.1Mpa)
- b. Compressor Outer Radius~4.0 cm,
- Turbine Outer Radius~4.0 cm.
- c. System SCCO2 flow rate~3.0 Kg/sec.
- e. Turbine Shaft RPM~30,000 rpm.
- f. Heat Source Temp.~350 C

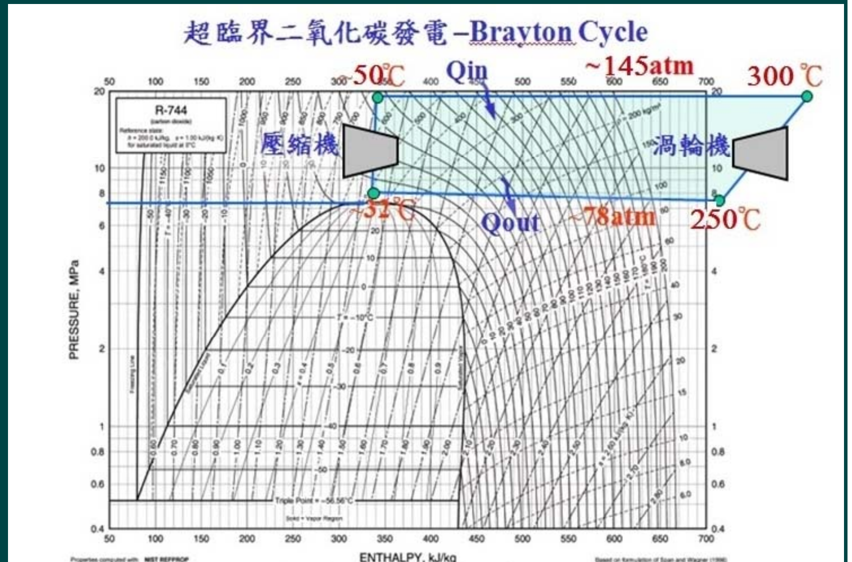
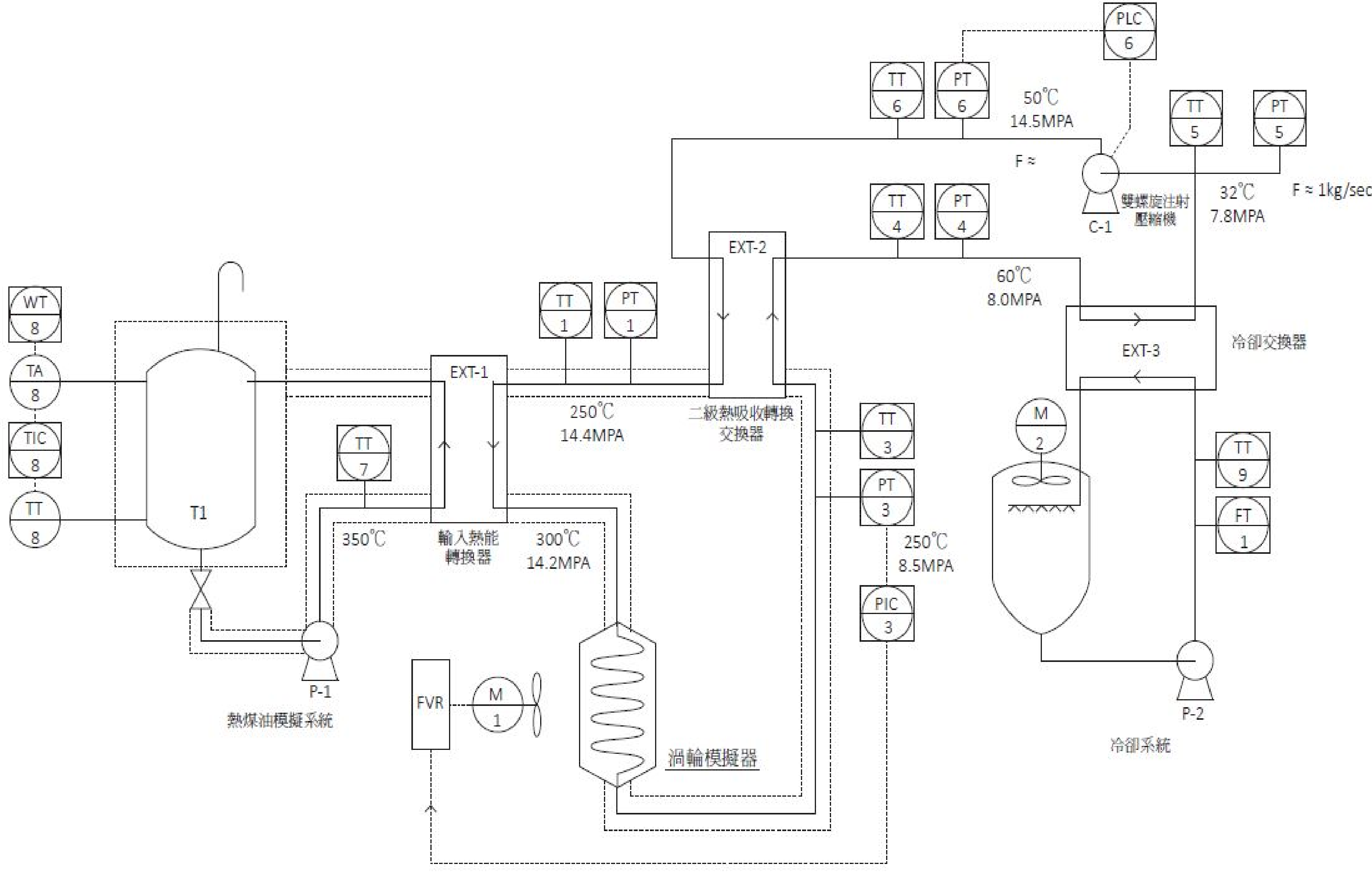


Fig. 18 Pressure-Enthalpy Diagram for Refrigerant 744 (Carbon Dioxide)

1. ASHRAE Handbook, 2009.
2. Span, R. and W. Wagner, 1996."A new equation of state for carbon dioxide covering fluid region from triple-point temperature to 1100 K at pressures up to 800 Mpa. J. of physical and Chemical Reference Data 26: 1509-1596.
3. Robert Z. Litwin, "Supercritical CO2 turbine for use in solar power plants, US patent 7,6851820 B2 Mar. 2010.

10 kw SCO2 System Spec. & Design

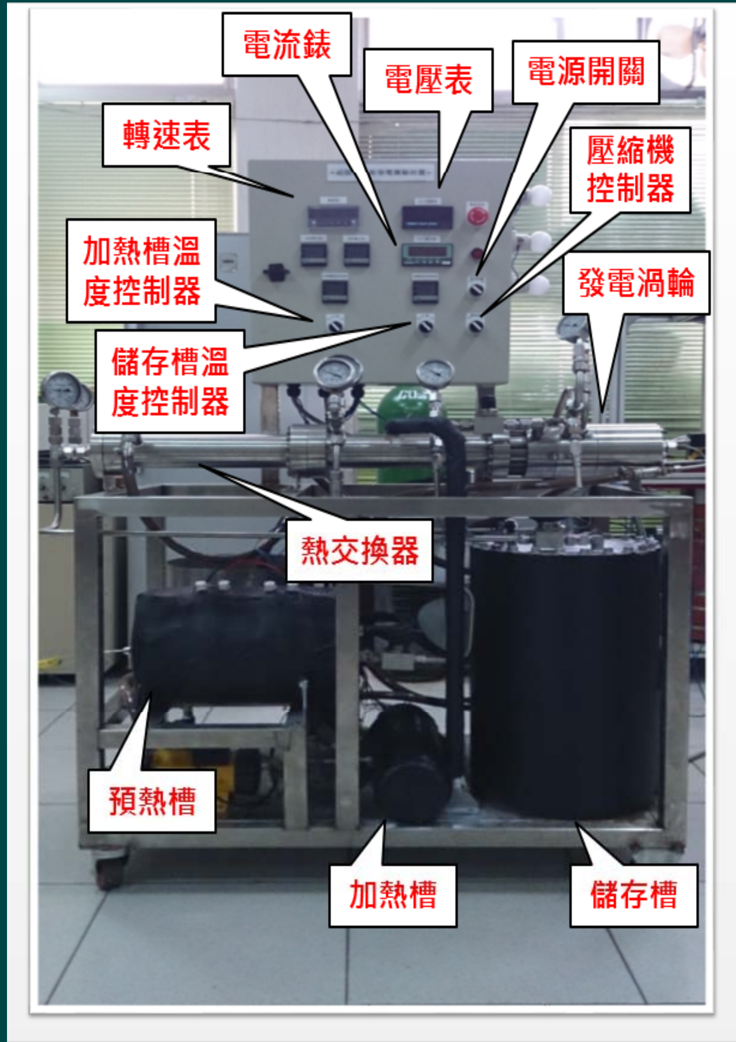


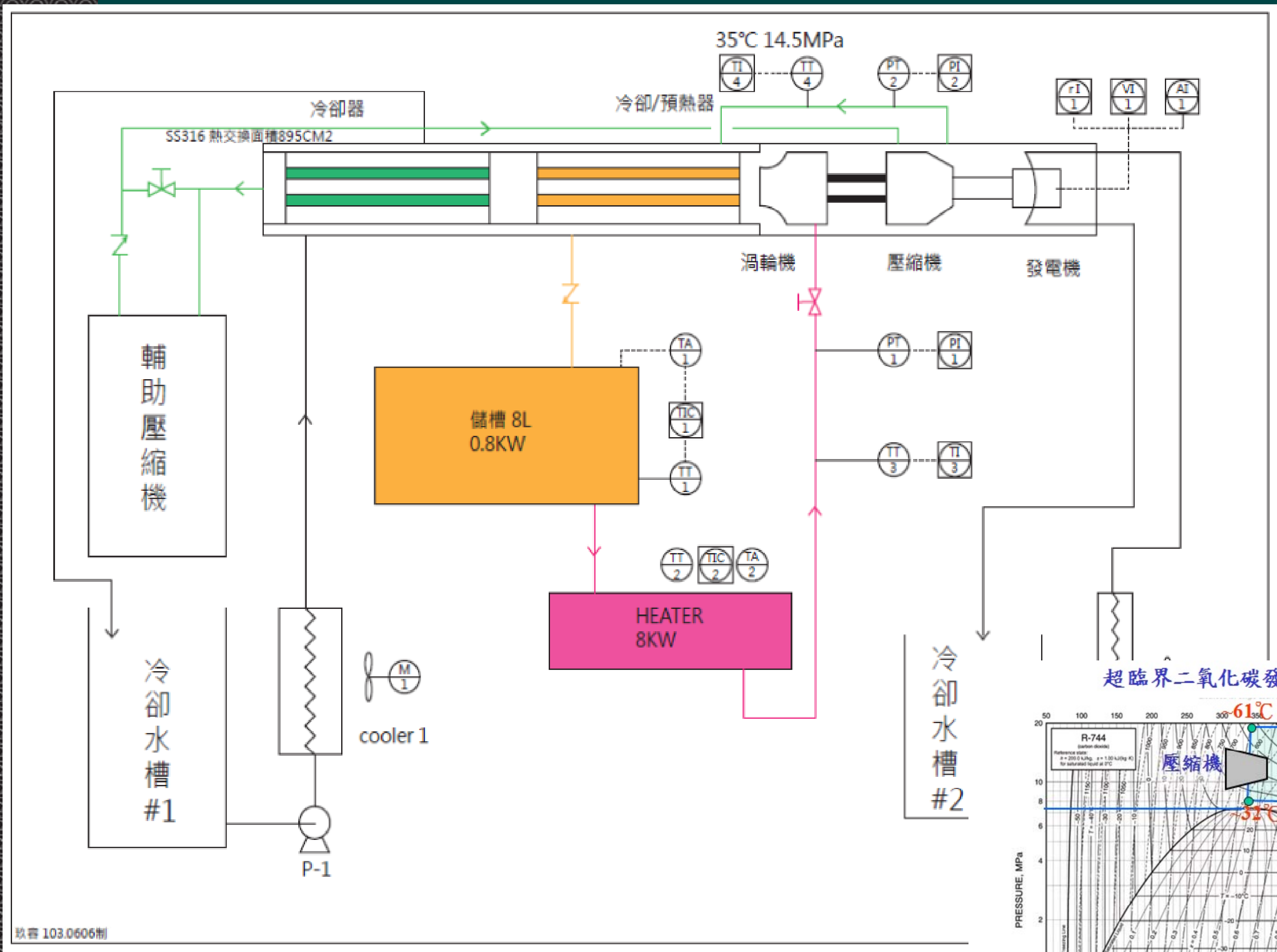
SCO2

Power System Development Approach

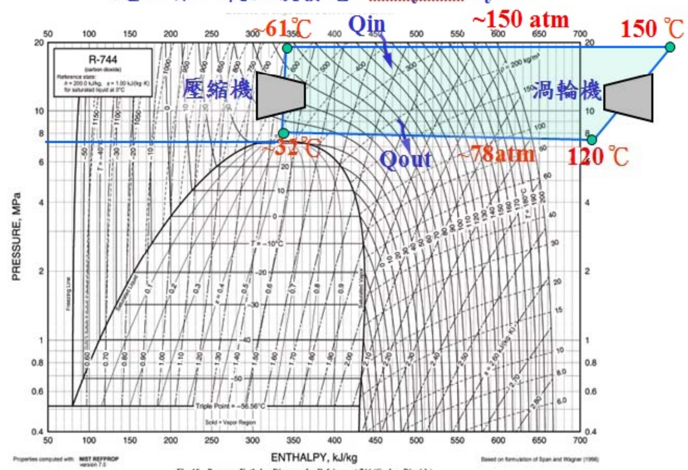
(1 kw→10kw → 250kw → Mw)

- Small Prototype R&D :
- I Kw power output from Waste Heat
- Using Brayton power cycle
- CFD Analysis of Compressor and Turbine Performance in SCCO2 Flowfield
- Design and Fabricate a Portable System
- Test and Assess the following technologies required





超臨界二氧化碳發電–Brayton Cycle



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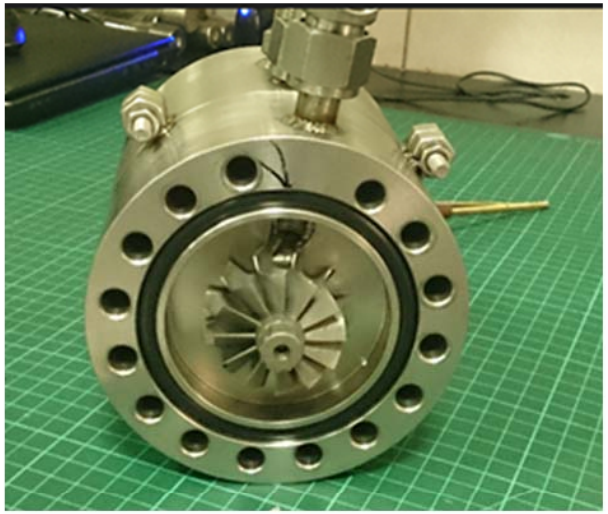
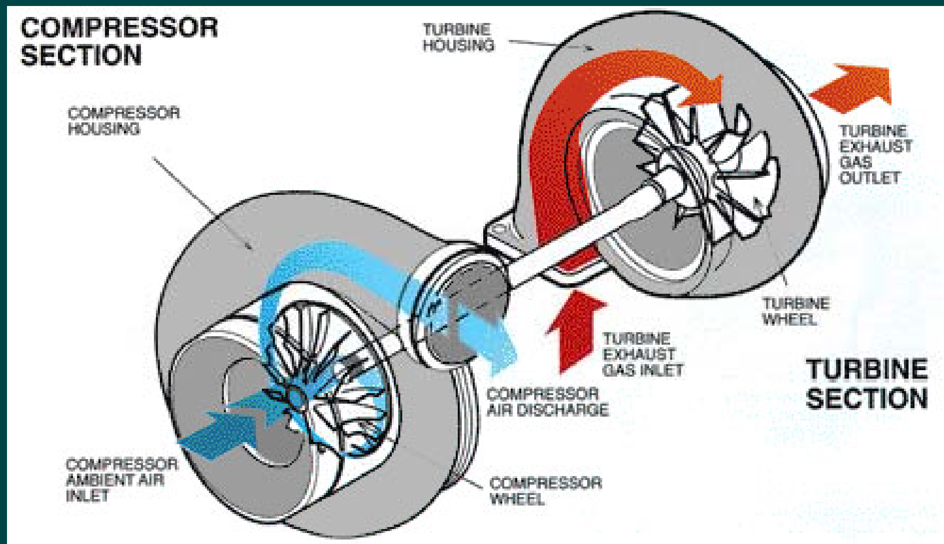
TAC Component

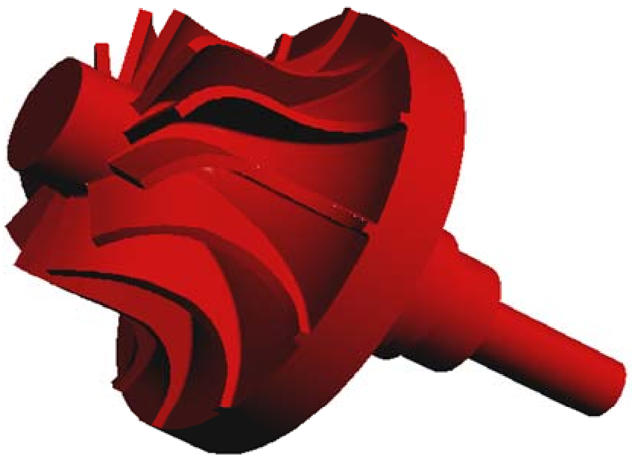
渦輪與壓縮機結合發電機組合圖



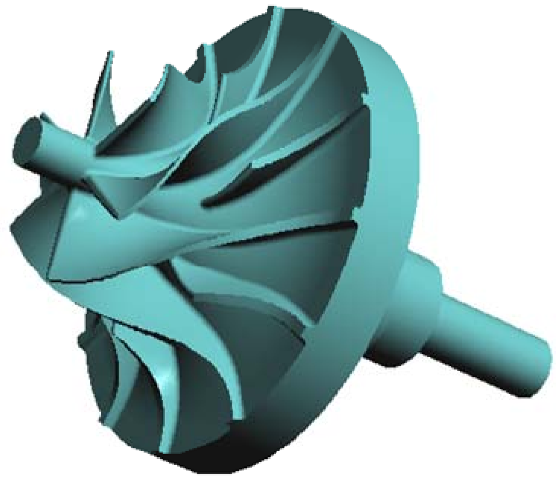
渦輪與壓縮機安裝組合圖



Designed Compressor & Turbine



3D渦輪及製造圖



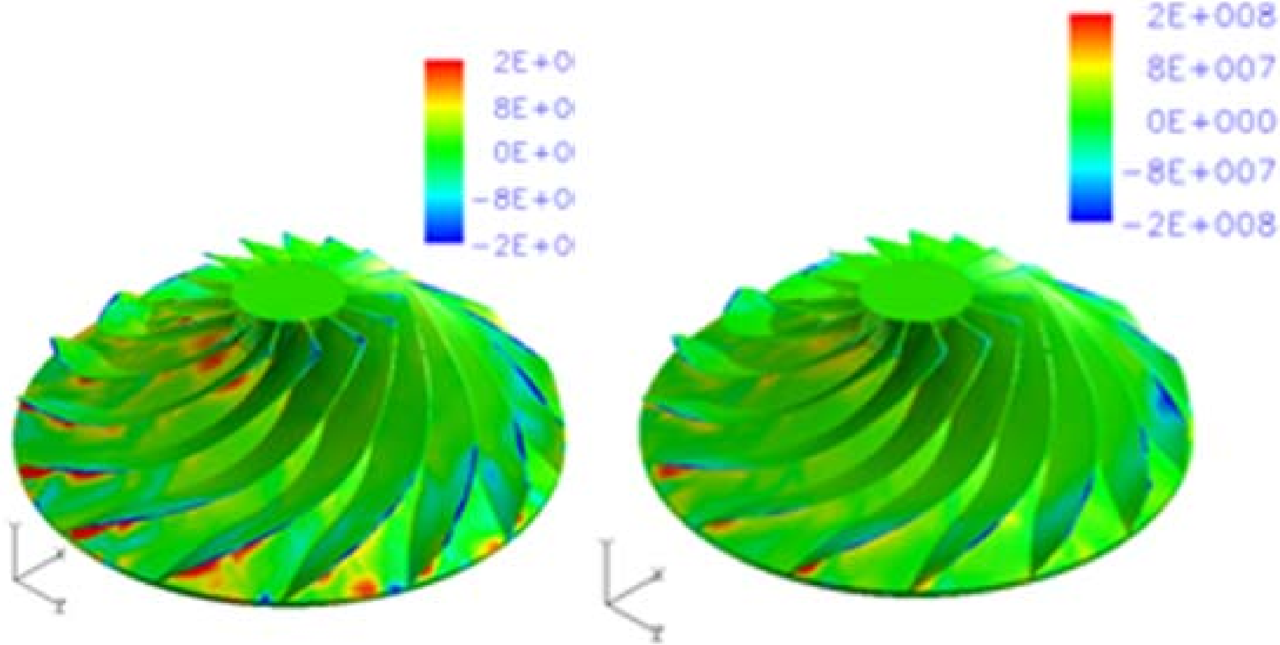
壓縮器3D製造圖

CFD Simulation of Compressor & Turbine Flowfield

- Governing Equation:
- Mathematical Model Adopt Time-Dependent Reynold's Navier-Stokes Equations；
- Using discrete finite-volume Method coupled with Compressible Implicit Approaching Scheme，

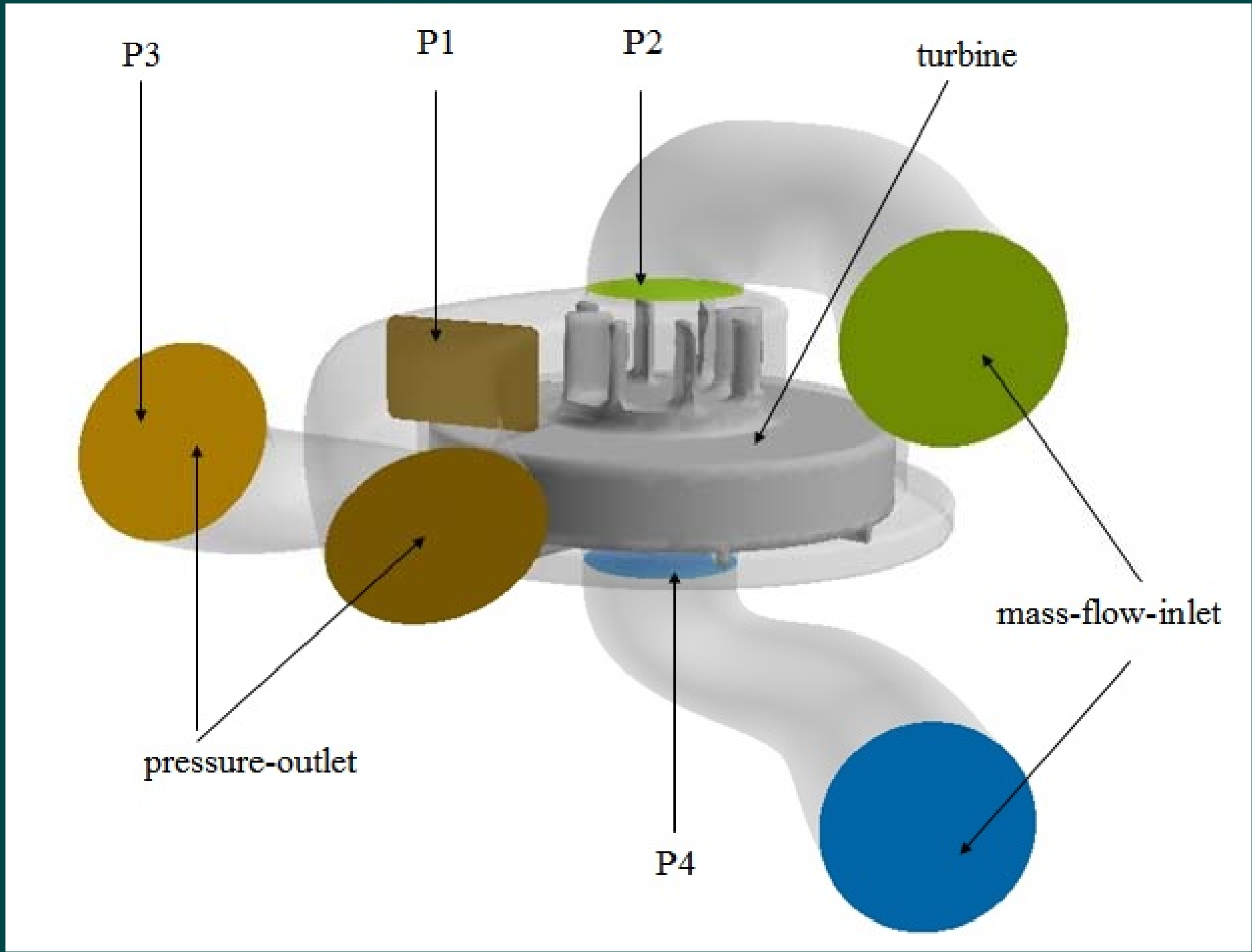
$$\frac{\partial}{\partial t}\iiint_{\Omega} U d\Omega + \oiint_{S} \vec{\Phi} \times d\vec{S} = 0$$

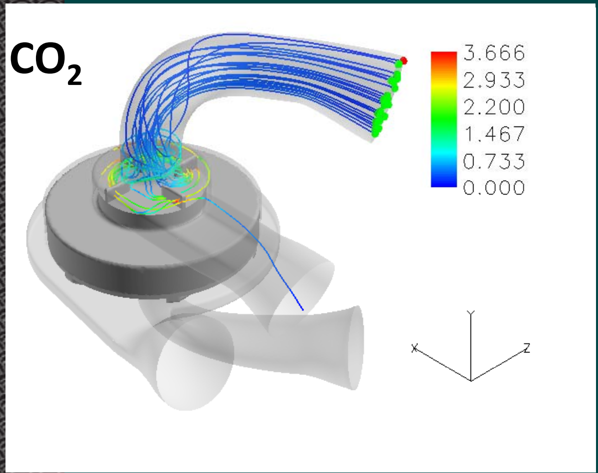
Turbine Surface Pressure Distribution

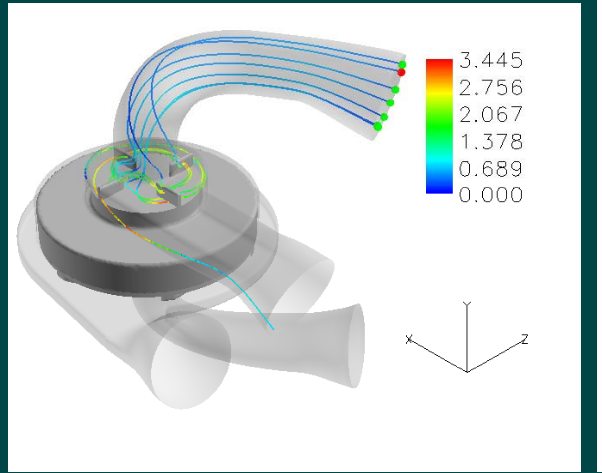


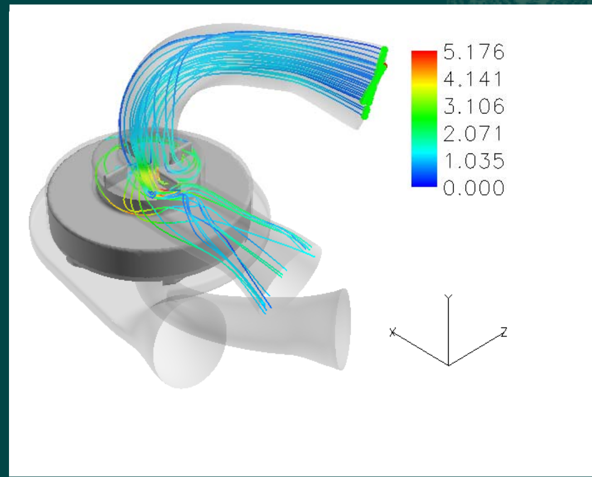
(a) air flow (b) scco2 flow

Compressor-Turbine System Flowfield Simulation





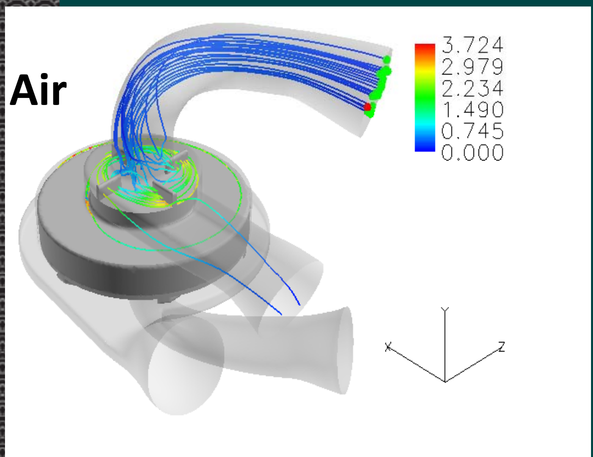


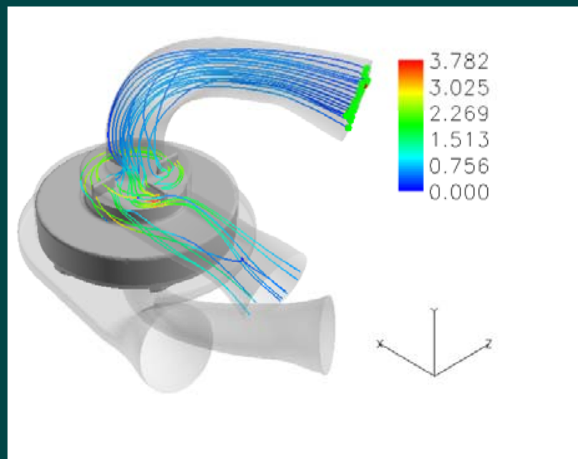


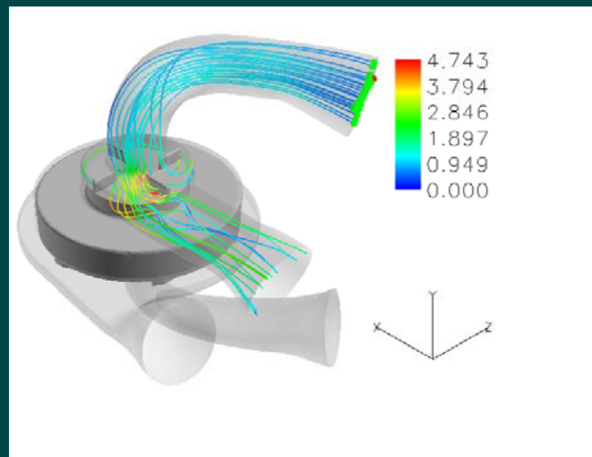
25Kgw/min

50 Kgw/min

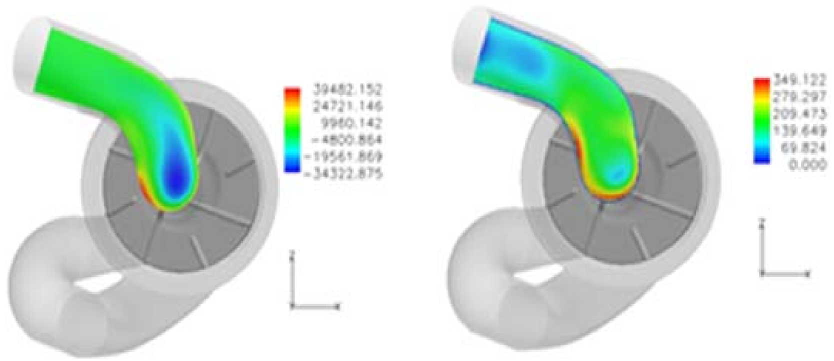
100 Kgw/min



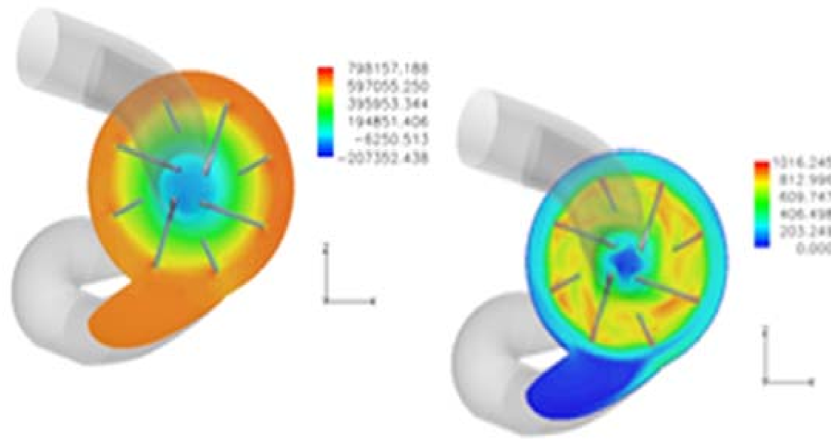




27,000 rpm

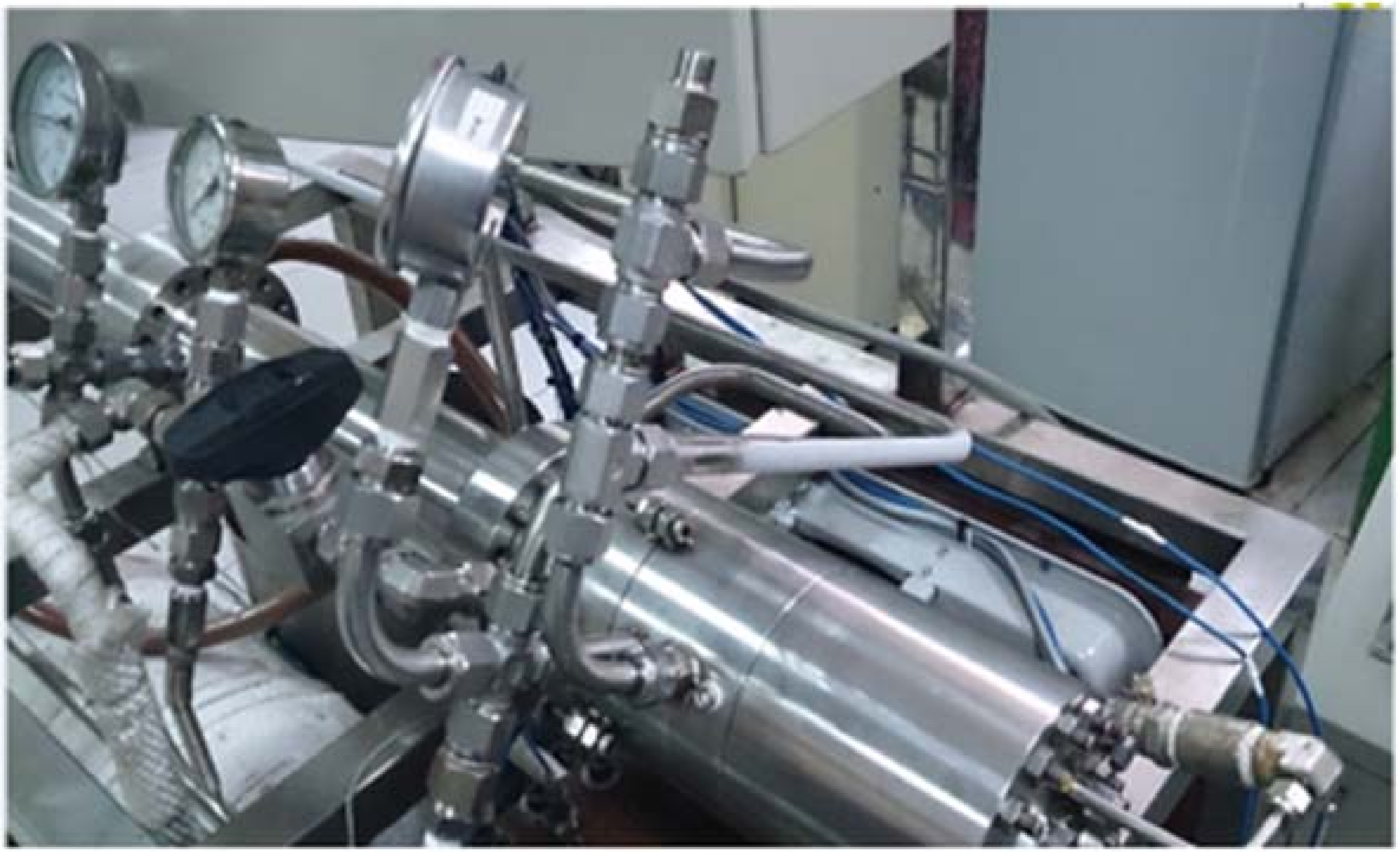


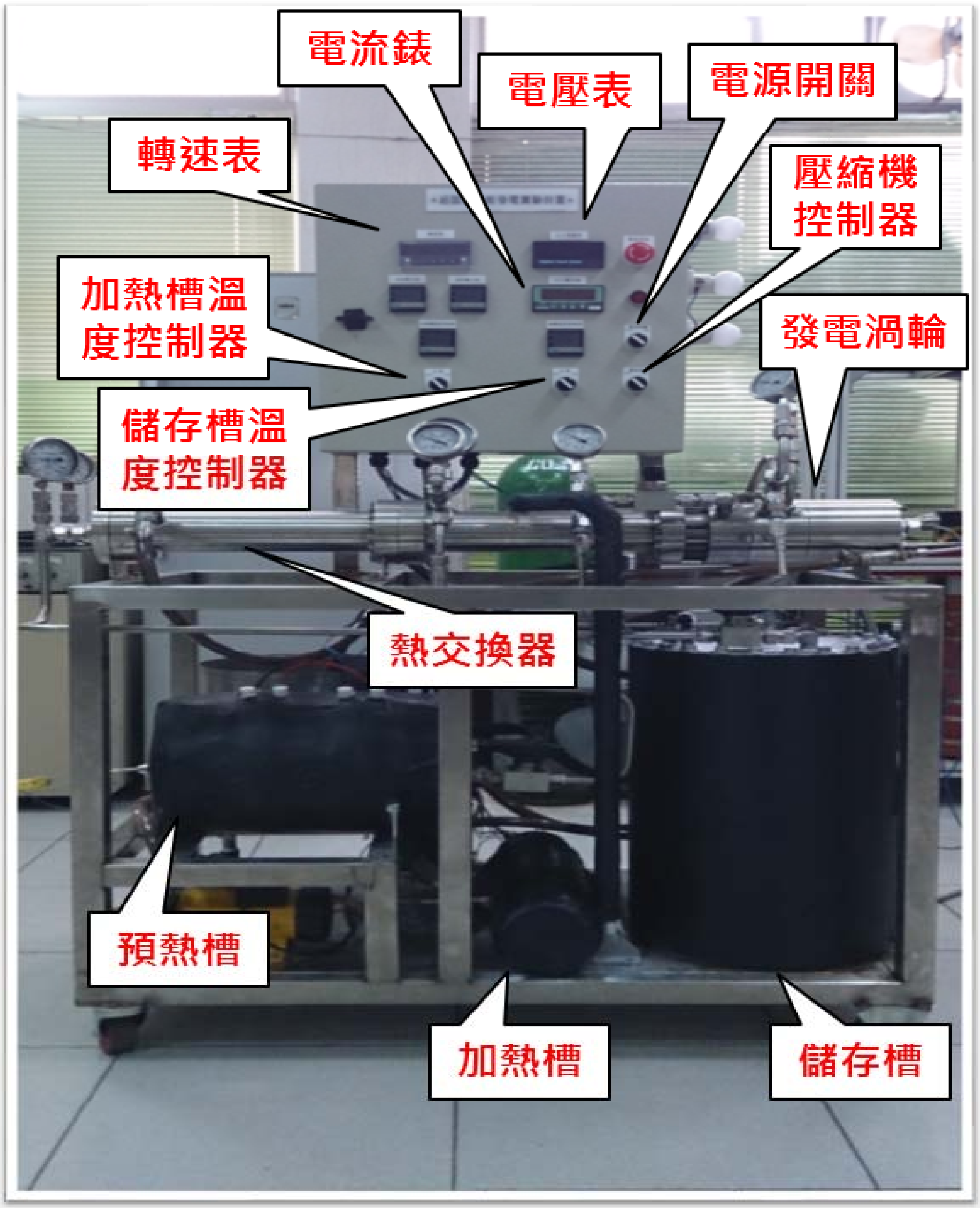
壓縮段進氣流道之壓力及流速分佈



壓縮段葉輪上表面切面壓力及速度分佈

Turbine-Alternator-Compressor Section





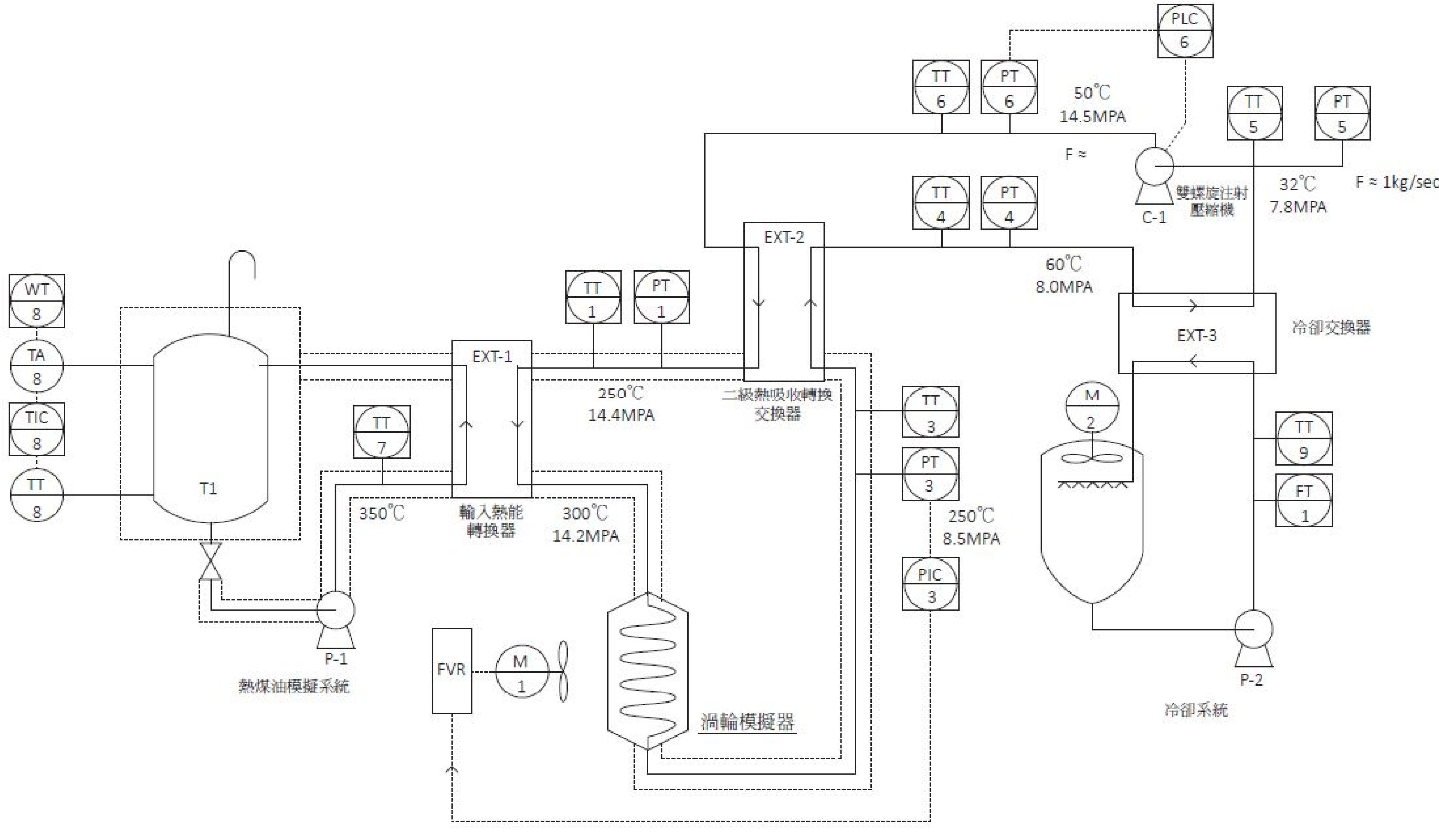
電流錶
電壓表
電源開關
轉速表
壓縮機
控制器
加熱槽溫
度控制器
發電渦輪
儲存槽溫
度控制器
熱交換器
預熱槽
加熱槽
儲存槽

Test Data showing Temperature, Current and Voltage

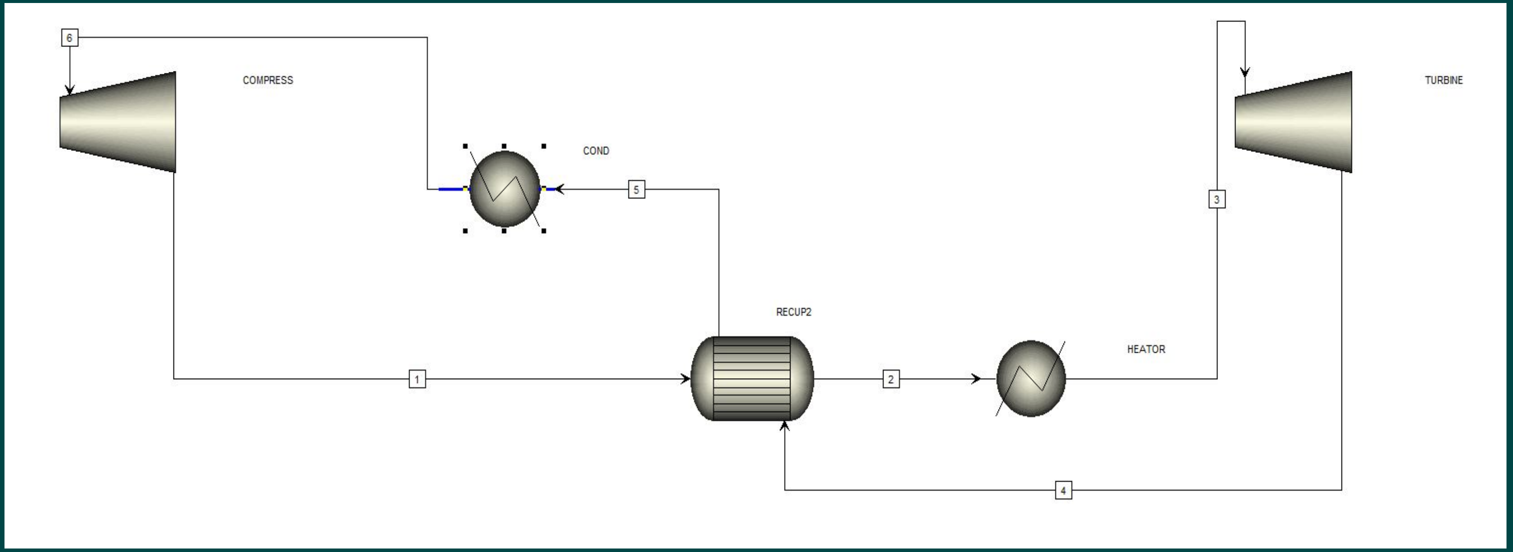
Results & Suggestions

- As turbine inlet temperature T~150 C, and pressure difference ΔP between turbine inlet & outlet reaches ΔP＞30Kg/cm2, the system can start running.
- The maximum Voltage output is V~125 v, Current I~5 amp, Rotation speed R~10,000 rpm.
- The test condition is not stable and can not offer sustained power output yet.
- Estimated improvement includes: heat exchanger, heat source, compressor--turbine flow & system piping…

10 Kw System Aspen Plus Analysis & Flow chart



Aspen Plus Simulation



Reference results

state	1	2	3	4	5	6
Pressure (MPa)	14.5	14.5	14.2	8.5	8	7.8
T(K)	323	475	580	523	330	305

Simulation results

state	1	2	3	4	5	6
Pressure (MPa)	14.5	14.5	14.2	8.5	8	7.8
T(K)	321.95	438.03	579.85	530.74	326.95	304.85

Turbine efficiency: 85% (assumed)

Compressor efficiency: 78% (assumed)

Turbine output	43.7kW
Net work output	30.9kW
Heat to Power efficiency	34.8%
Net efficiency	**27.6%**

Turbomachinery

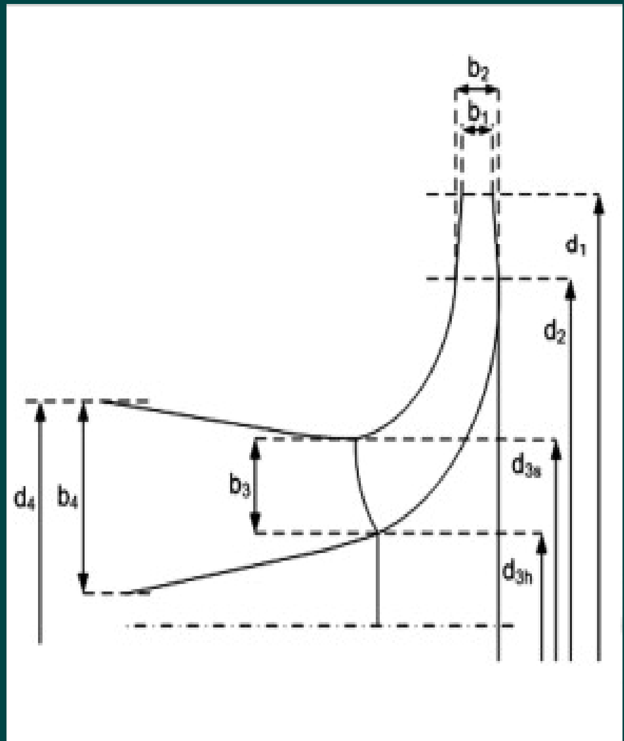
Mass flow:1kg/s

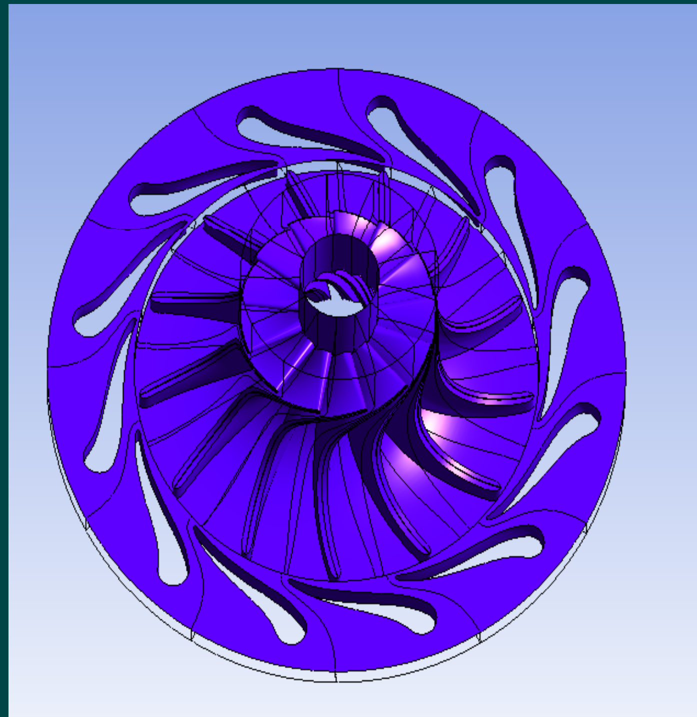
Rotation rate:

30000 rpm

Blade number:13

Inducer number:12



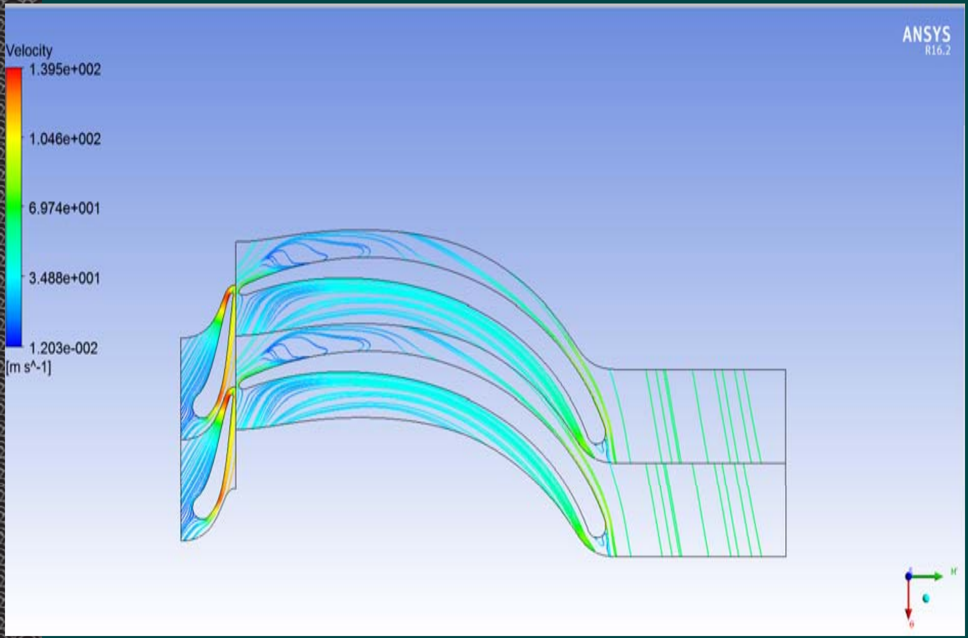


d_2=24

d_3=12

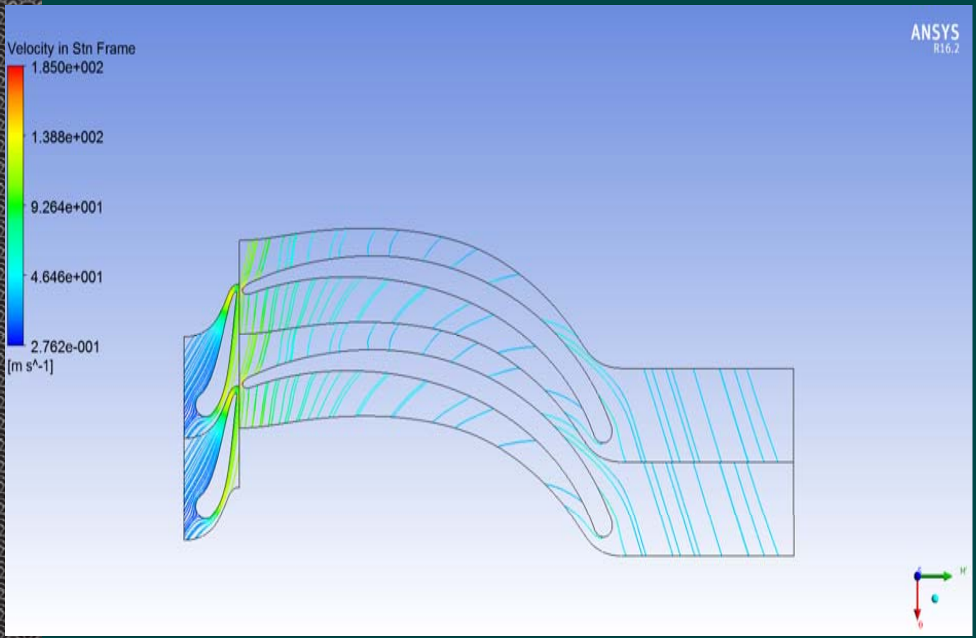
d_{3h}=4.8

b_1= b_2=3(mm)



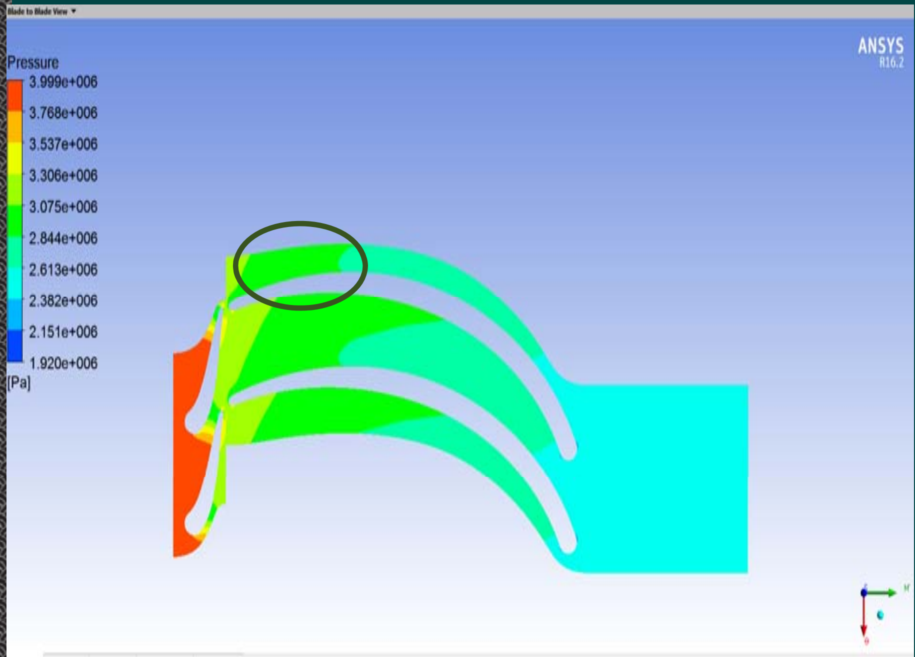
RFR frame

- Rotor entrance angle (~40°)
- Vortex affect dynamic movement



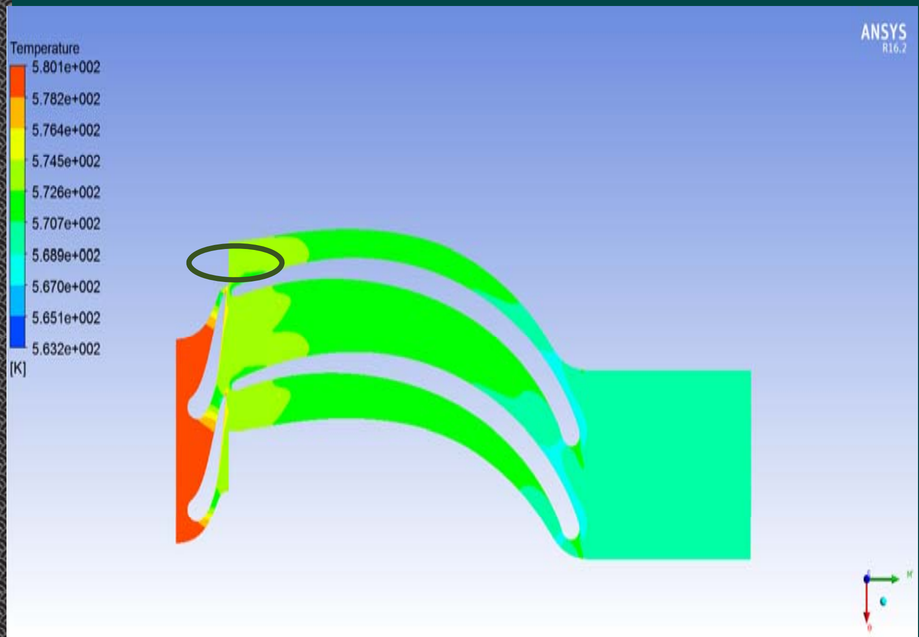
Stn frame

- Outlet streamline not axial direction
- Dynamic Energy loss



Model pressure

- Vortex cause pressure drop
- Pressure drop caused by large incident angle

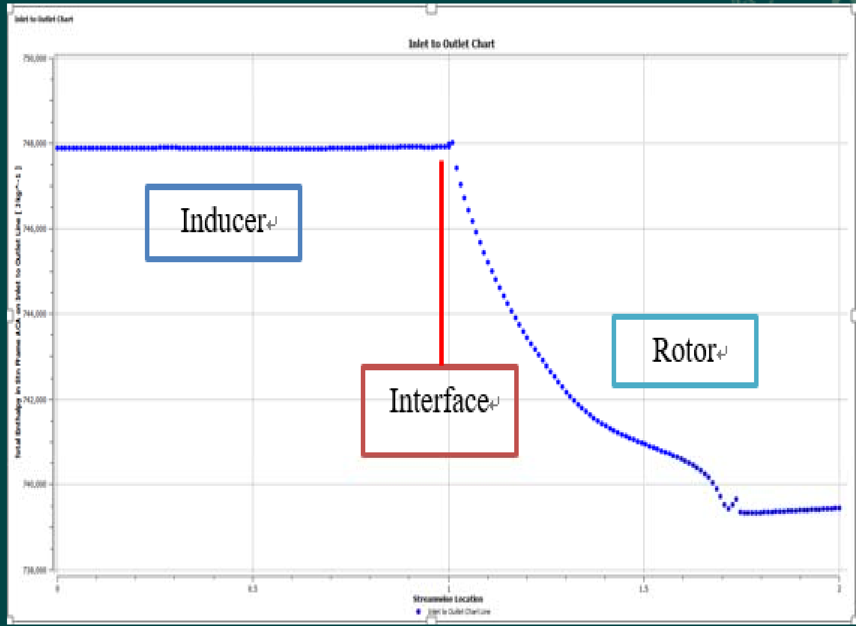


Model temperature

- Vortex also cause temperature non-continuous

$\dot{m} = 1kg/s$ 30000RPM	Design model		
	Inducer inlet	Interface	Rotor outlet
Static pressure (MPa)	14	13.2	12.55
Static temperature (K)	580	573	569
Velocity in Stn frame (m/s)	13.38	106.4	39.28
Density (kg/m^3)	131.7	125.9	120.7

渦輪設計站位圖



Total enthalpy chart

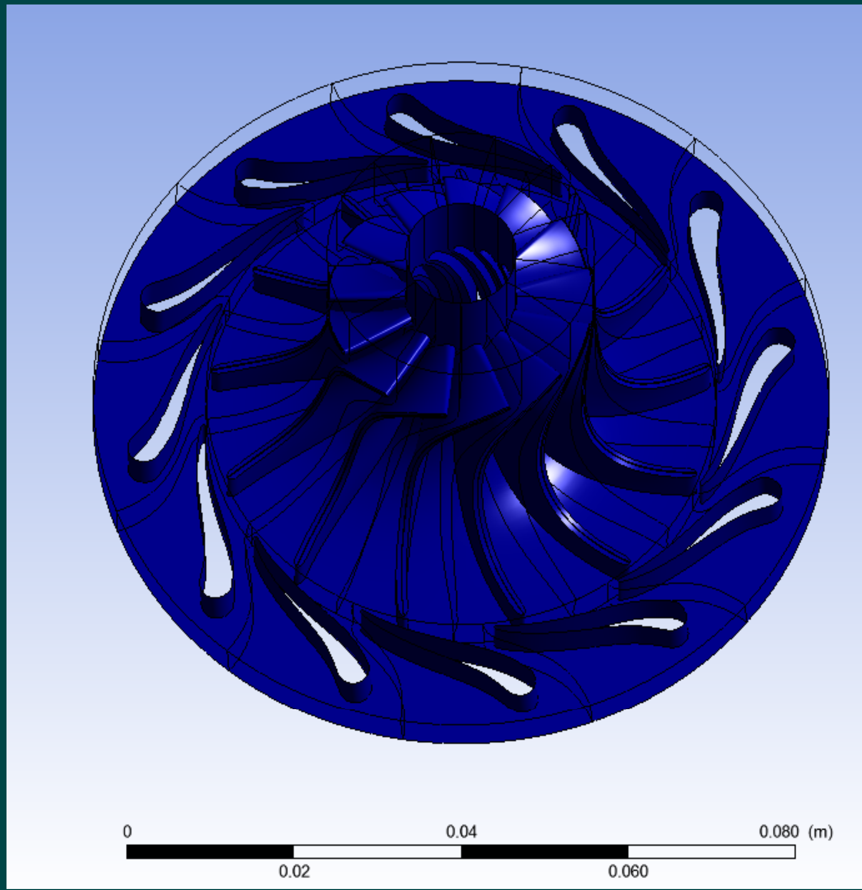
- 導引葉片階段能量僅在不同型態間轉換無流失，直到進入轉子後能量轉為輸出功開始減少至出口緩衝區停止

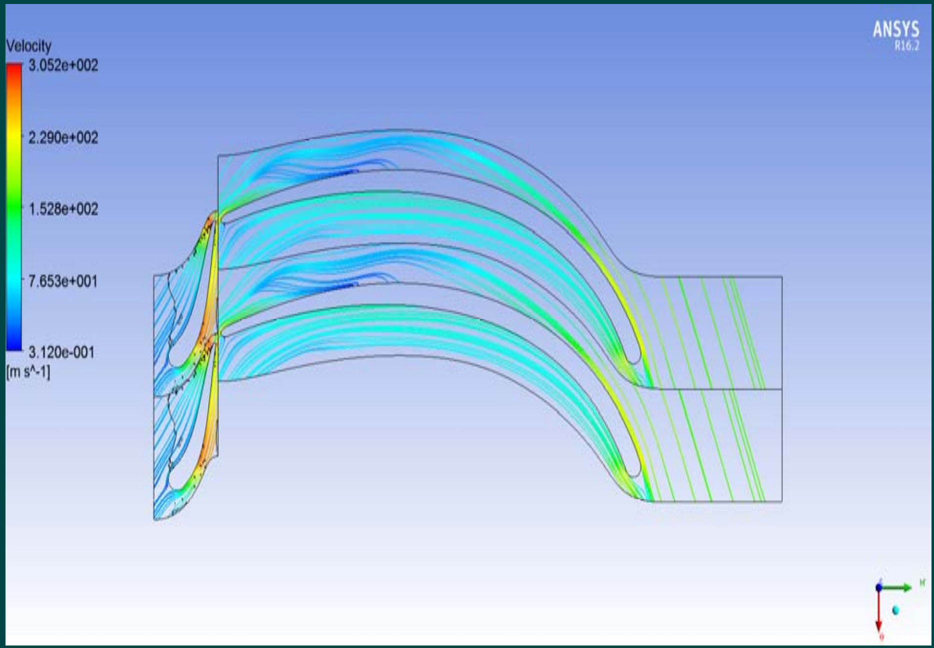
Modify the Design parameters

Flow Rate increase to 3.1kg/s、
Rotation speed to 50000RPM

- Mass flow: 3.1kg/s
- Angular velocity: 50000 rpm
- Blade number:13
- Inducer number:12

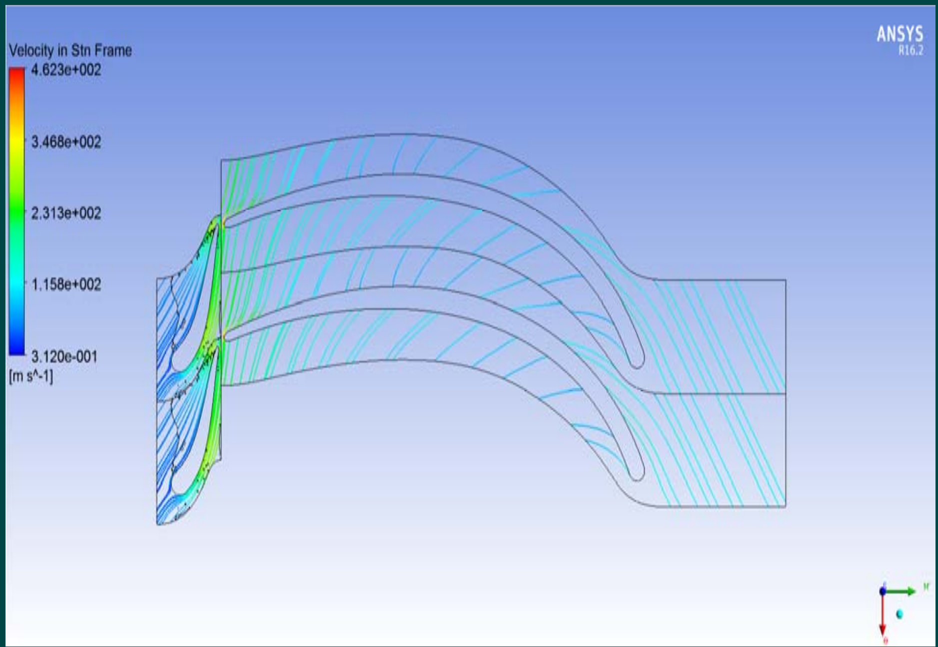
d_2=30
d_3=16
d_{3h}=6.6
b_1= b_2=4(mm)





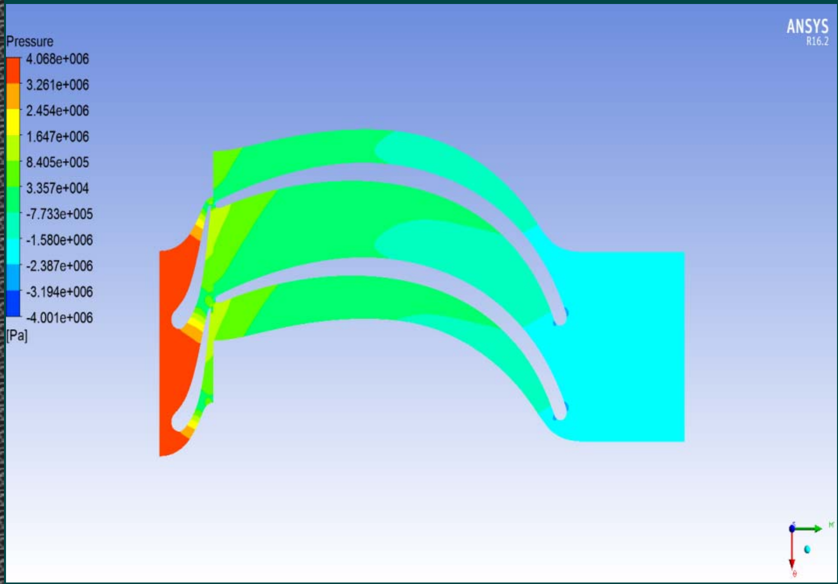
RFR frame

- Rotor entrance angle (~20°)
- Less vortex zone



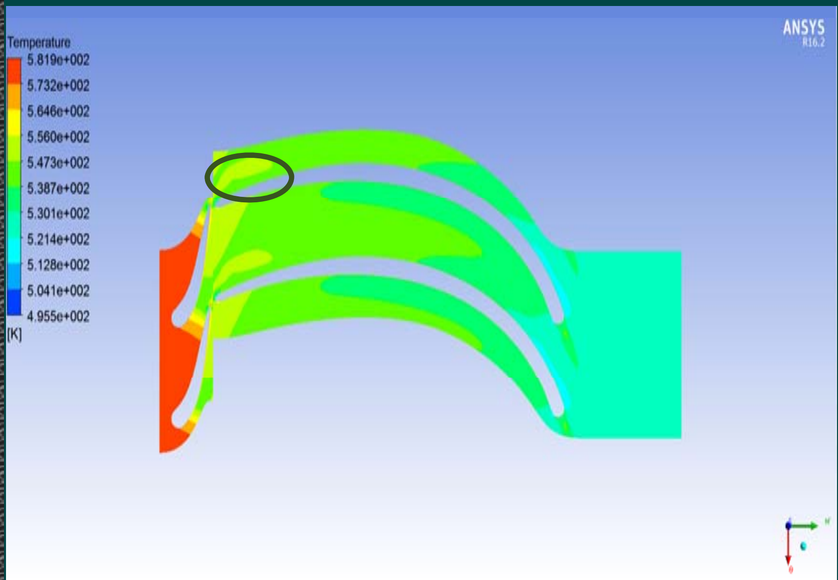
Stn frame

- Exit streamline direction need improved



Model pressure

- Less pressure drop zone
- 轉子壓降集中在葉片中後段

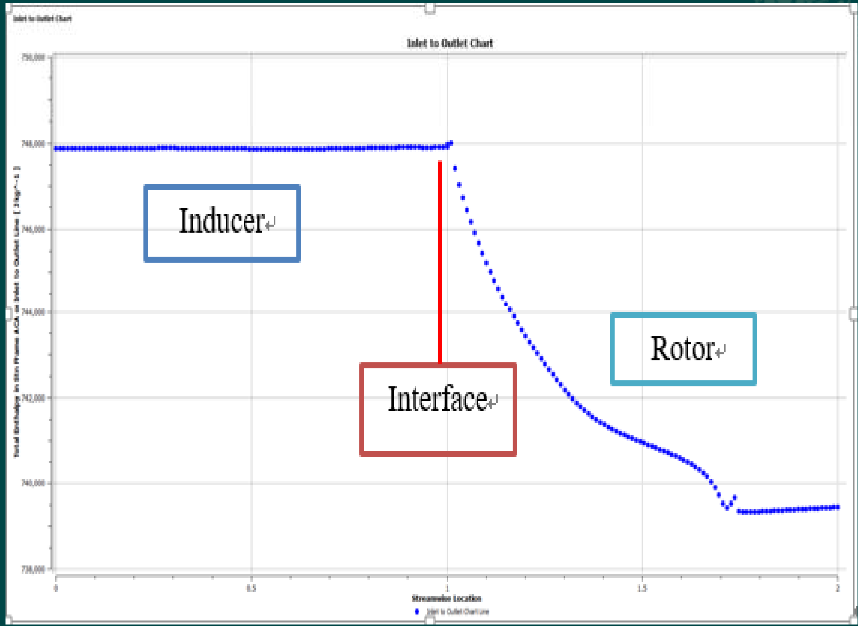


Model temperature

- Less temperature drop zone

$\dot{m} = 3.7kg/s$ 50000RPM	Design model		
	Inducer inlet	Interface	Rotor outlet
Static pressure (MPa)	14	10.53	8.1
Static temperature (K)	580	550.5	528.8
Velocity in Stn frame (m/s)	42.8	236.1	109.7
Density (kg/m³)	131.38	105.2	84.5

渦輪設計站位圖



Total enthalpy chart

Integated Starter & Generator Design

Development of a High-speed permanent magnet electrical machine

Characteristics of the PMSM Specifications

- High power density and high efficiency levels
- High power factor and thus power saving
- ability to provide starting torque
- Reduction of volumes
- Low rotor losses and low copper losses

design parameter	technical value
rated speed	30,000 rpm
output power	10 kW
efficiency	>92%
supply frequency	500 Hz
induced voltage	220 V

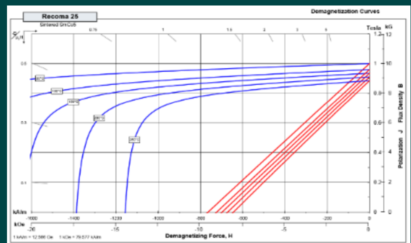
Selection of silicon steel and permanent magnet for specific operating environment

Silicon steel : 10JNEX900

- suitable for high-frequency condition
- low core loss
- High permeability
- low magnetostriction and stable quality

material	thickness (mm)	specific resistance (μΩ.m)	saturation magnetization (T)	coreloss(400 Hz,1T) (W/kg)
10JNEX900	0.1	0.82	1.8	5.7
grain oriented Si steel	0.1	0.48	2	6.4
Fe base amorphous	0.025	1.3	1.5	1.5

- suitable for high temperature environment
- high residual induction and coercive force

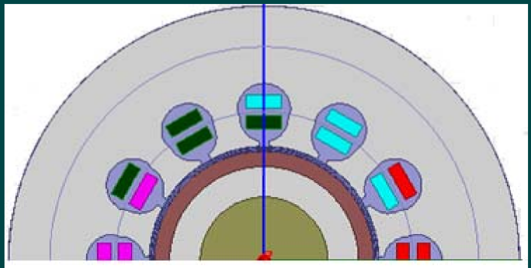


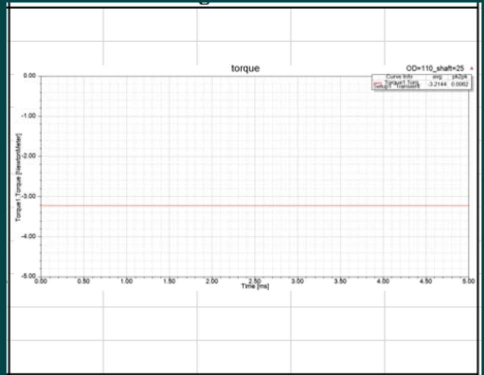
	Characteristic	Units	min.	nominal
Magnetic Properties	**Br**, Residual Induction	Gauss	9,700	10,000
		Tesla	0.97	1.00
	H_{cB}, Coercivity	Oersteds	9,050	9,740
		kA/m	720	775
	H_{cJ}, Intrinsic Coercivity	Oersteds	25,000	30,000
		kA/m	2,000	2,400
	BHmax, Maximum Energy Product	MGOe	23	25
		kJ/m^3	180	200

Development of a High-speed Permanent Magnet Electrical Machine

Design result

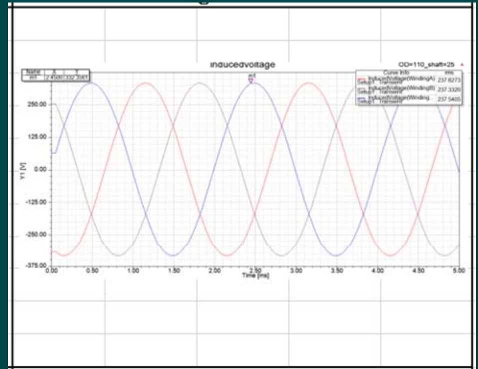
Taking the empirical analysis into consideration with the simulation of the **ANSYS EM Maxwell** software has led to the development of the model in figure 1.





$T_{avg} = -3.214(N.m)\ ;\ T_{ripple} = 0.0062(N.m)$

Fiqure2.rated output torque in the PMSM



$V_{rms} = 237.5\ V$

Fiqure3.induced voltage in the PMSM

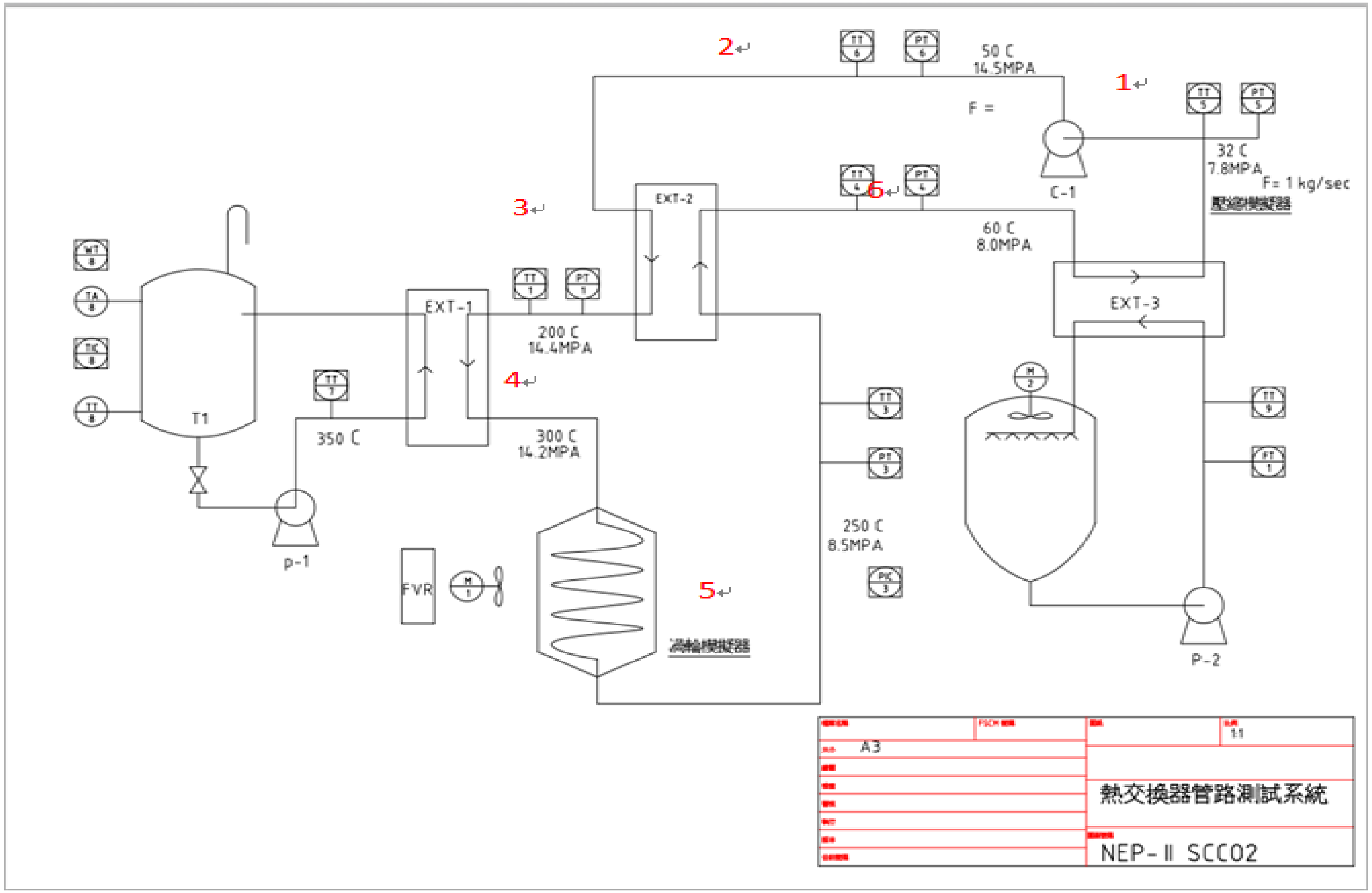
Fiqure 1. Model of the 50000 rpm 10 kw permanent magnet machine

Through simulation, the rated output torque and induced voltage of figure2. and figure3. was developed. It shows that the ripple torque were relatively small and smaller harmonic components.

The most important geometrical data and details concerning simulations are summarize in below.

geometrical data		simulation results	
outer stator diameter(mm)	120	speed(rpm)	30,000
outer rotor diameter(mm)	50	power(kW)	10
air gap(mm)	1	torque(N.m)	3.2
active length(mm)	150	voltage(rms)(V)	237
pole/slots	2/12	efficiency(%)	92

System Energy Balance Analysis



2. 系統熱交換器性能分析：

Design Assumption

refrigerant		carbon dioxide	
hot and cooling working fluid		Water	
Unit		Si with C	
refrigerant flow rate	m_r	1	kg/s
hot water flow rate	m_{hw}	5	kg/s
cooling water flow rate	m_{cw}	5	kg/s
hot water inlet temperature	T_{hi}	350	°C
Cooling water inlet temperature	T_{ci}	25	°C
hot water inlet PRESSURE	P_{hw}	0.6	MPa
Cooling water inlet PRESSURE	P_{cw}	0.101	kPa
isentropic efficiency of compressor	η_{comp}	0.7	
isentropic efficiency of turbine	η_{tur}	0.75	

temperature 1	T_1	32	°C
temperature 2	T_2	50	°C
temperature3	T_3	152	°C
temperature 4	T_4	300	°C
temperature 5	T_5	250	°C
temperature 6	T_6	60	°C

pressure1	P_1	7.8	MPa
pressure2	P_2	14.5	MPa
pressure3	P_3	14.4	MPa
pressure4	P_4	14.2	MPa
pressure5	P_5	8.5	MPa
pressure6	P_6	8	MPa

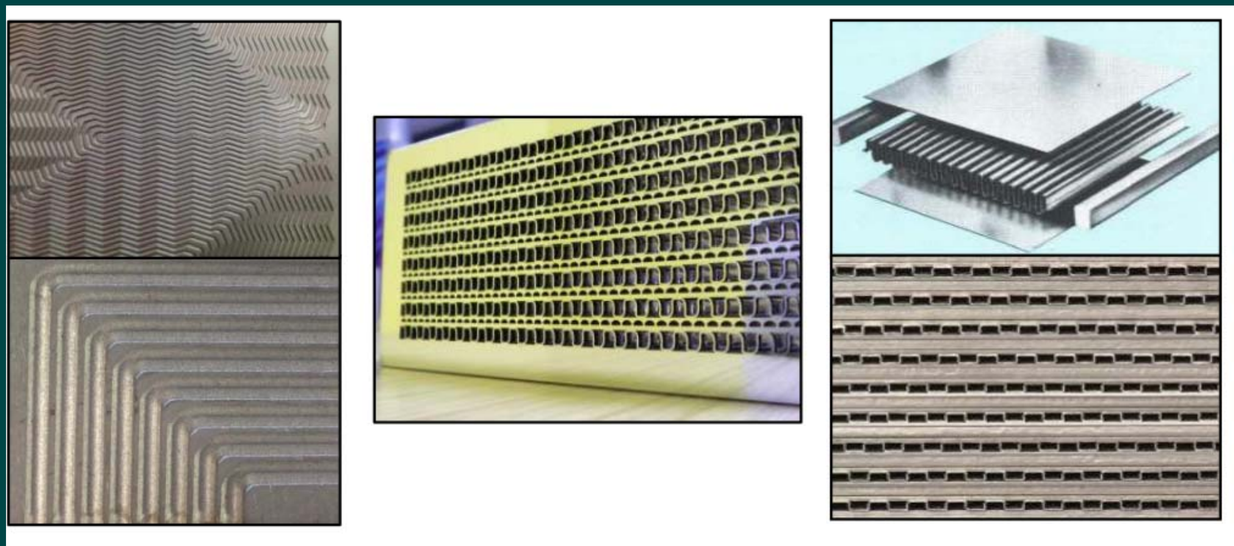
Heat Exchanger Analysis

Heat exchanger heat loads

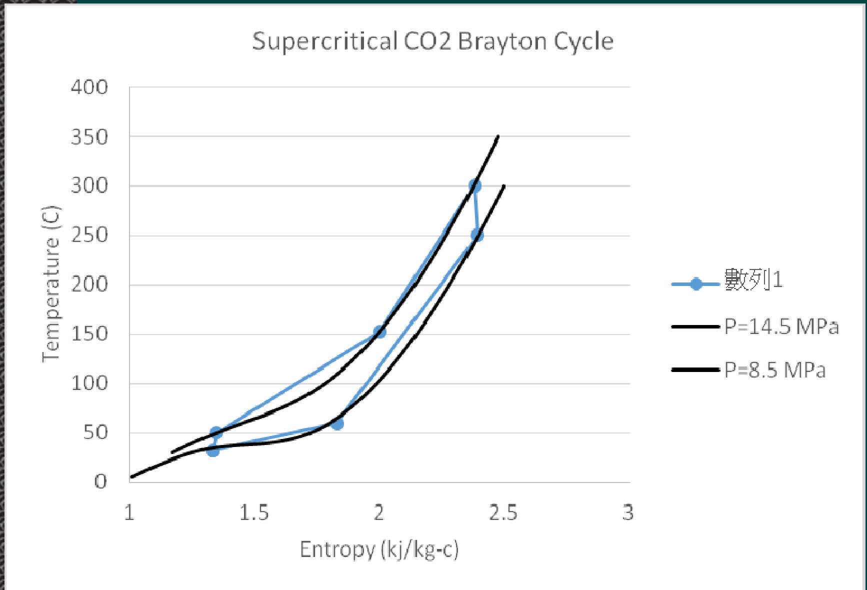
exchanger 1, heat load	*Q EX,1*	*186.2*	*kW*
Exchanger 3, heat load	*Q EX,3*	*156.2*	*kW*
exchanger 2, heat load	*Q EX2*	*236.6*	*kW*

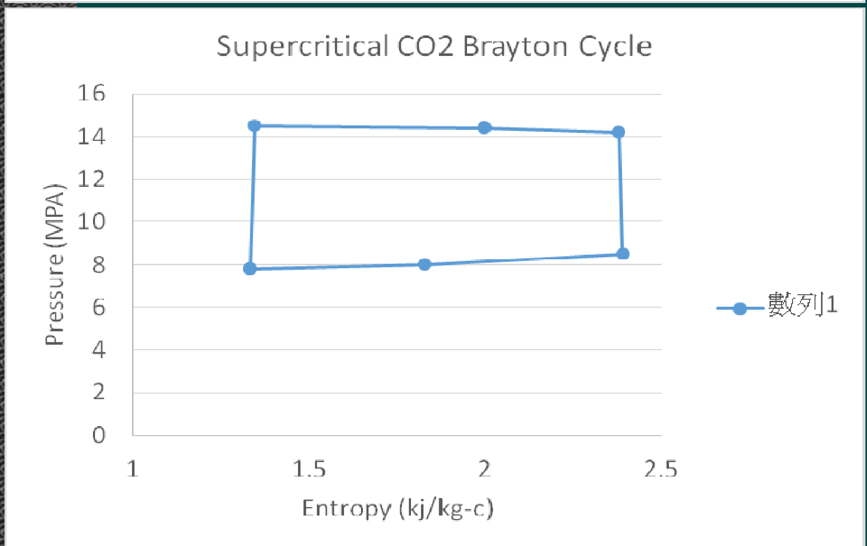
Work input and output

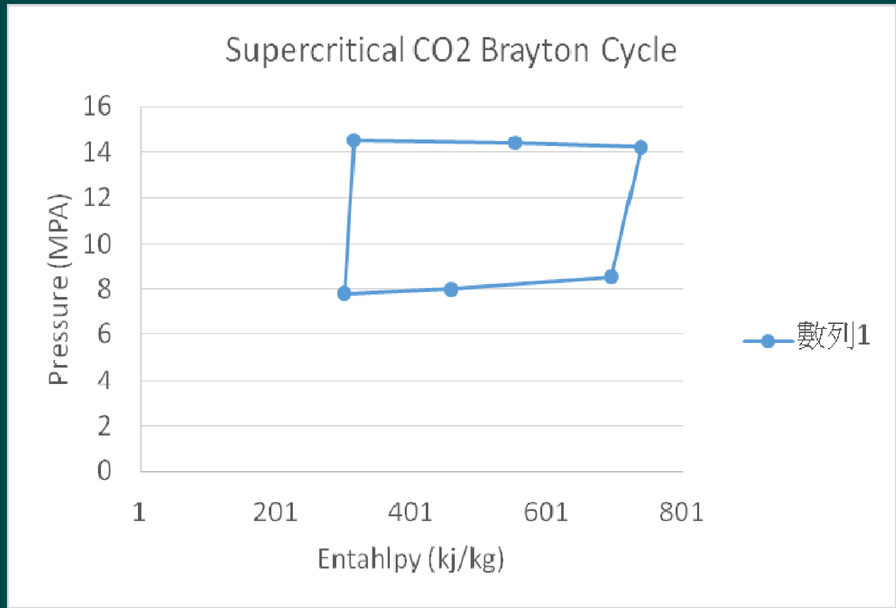
Compressor work input	W_{comp}	*10.2*	*kW*
turbine work output	W_{tur}	*44.3*	*kW*



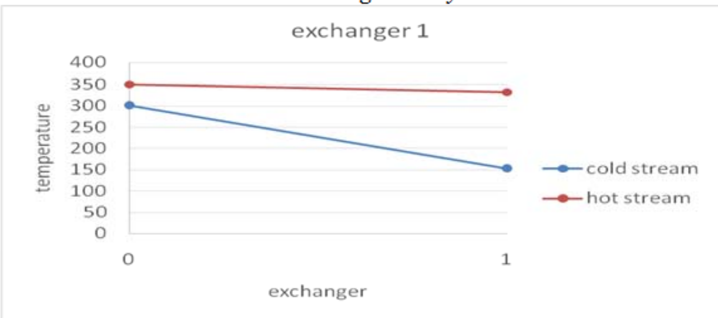
SCO2 Brayton Cycle Graphs

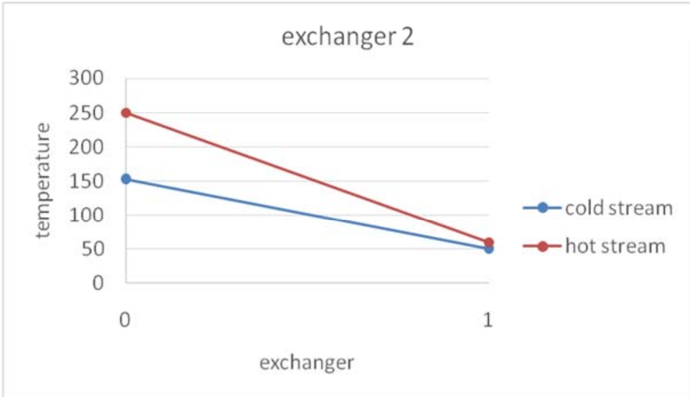


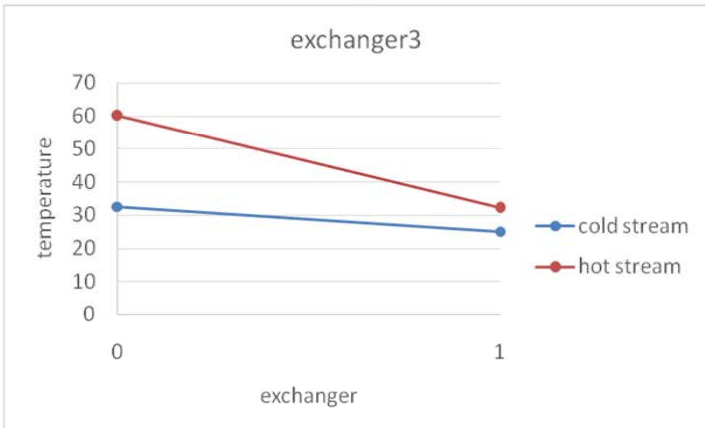




Heat exchanger Analysis







Typical Heat Exchanger type

KAORI

C202

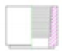
General Information

C type is the CBE, dedicated to R744 (CO_2), and compatible with heat pump and refrigeration system. The model has three types, including 70/100/140 BAR. The compact design plus outstanding thermal transfer efficiency and low pressure drop charaterize C series. C202 can sustain 140BAR and afford the pressure caused by R744 as thermal media. This capacity delights the COP value and results in "0 "ODP to protect the environment where we live. C202 can work well with pre-cooler and pervasive in various kinds of residential heat pump.

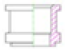
Industries

HVAC, Refrigeration, Heat Pump

Connection (up to)



Male Thread Female Thread



Solder

Depends on working condition

Applications

Evaporator,Condenser,De-superheater/Subcooler,Economizer, Pre-cooler/Pre-heater

Capacity Range

140.64KW

Specifications

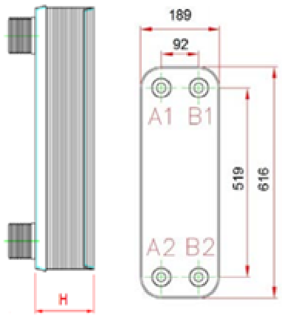
Standard Materials

Cover Plates	Stainless Steel
Connections	Stainless Steel
Plates	Stainless Steel
Braze Material	Copper

Standard Data

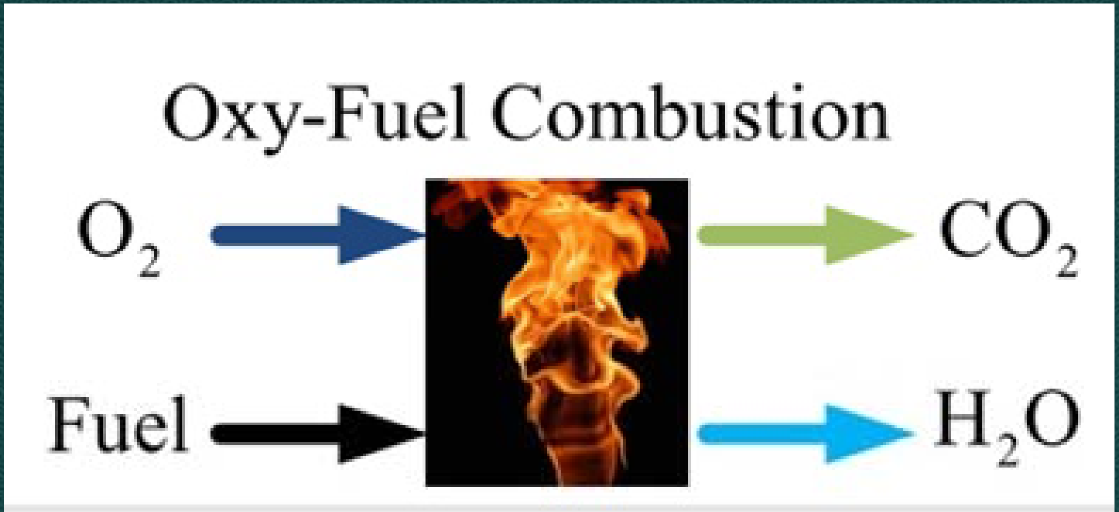
Max. working temperature °C	200
Max. working pressure (bar)	140
Min. test pressure (bar)	200
Max. flow rate (LPM)	720.00
Max. number of plates (N)	160
Plate Heat Transfer Area (M^2)	0.095 m^2
Thickness (mm) - H	14.0+2.15*N
Weight (kg)	12.41+0.755* N

(without connection)
N: Number of Plates

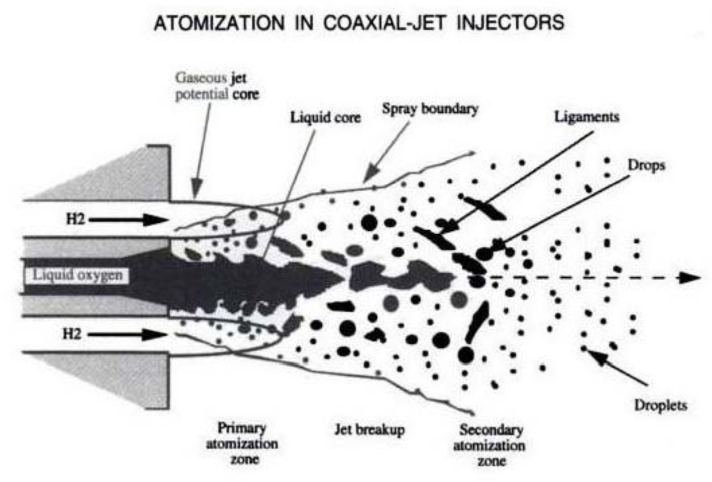


(size: mm)

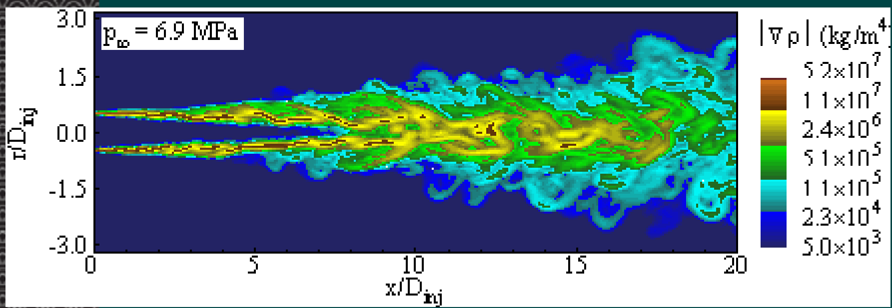
SCO2 Oxyfuel Combustor Analysis

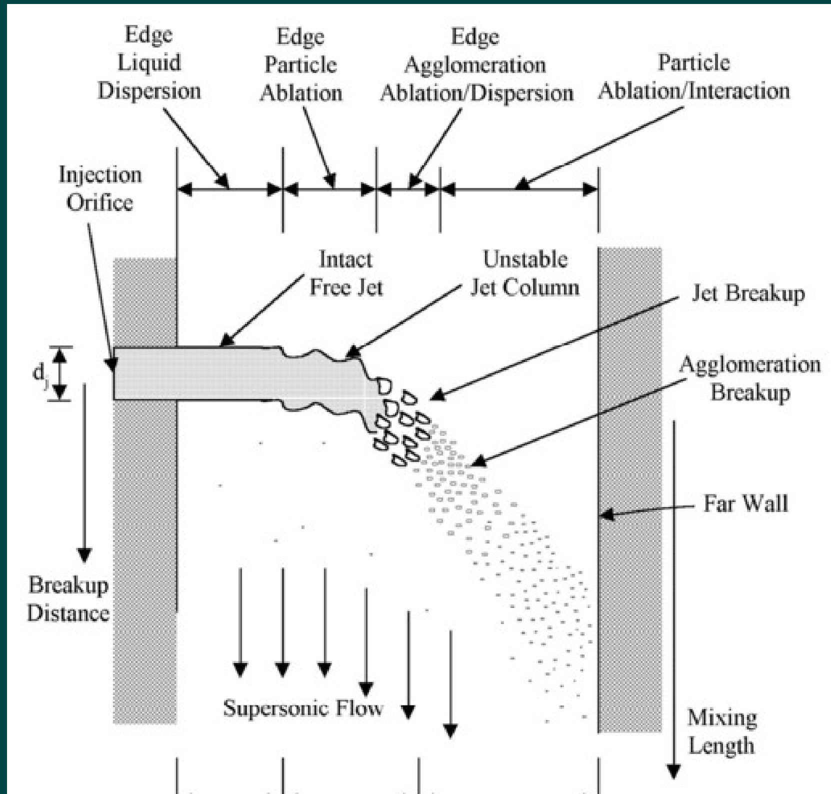


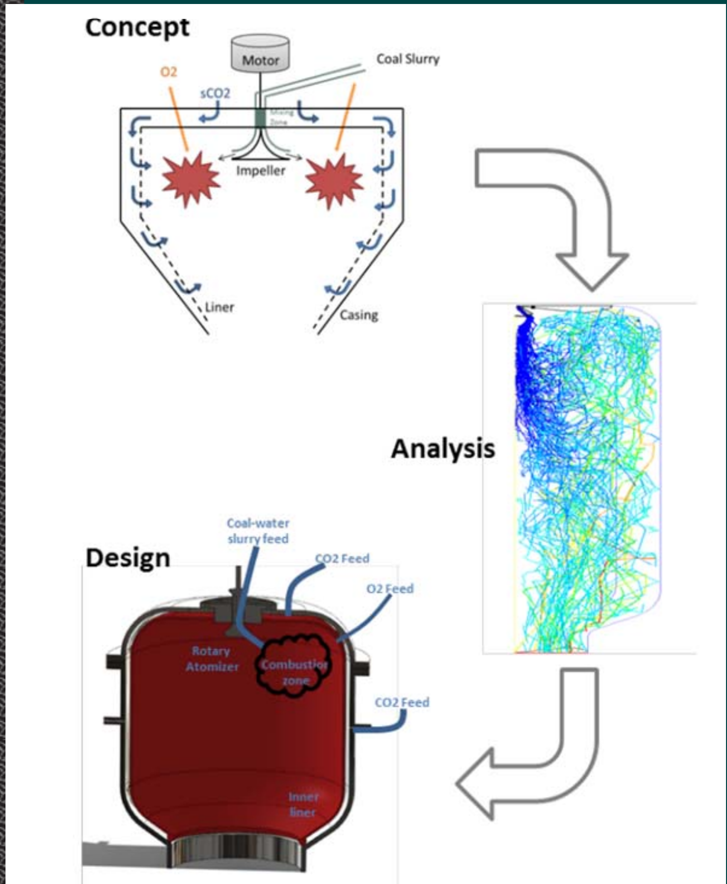
Different types of Fuel Injector

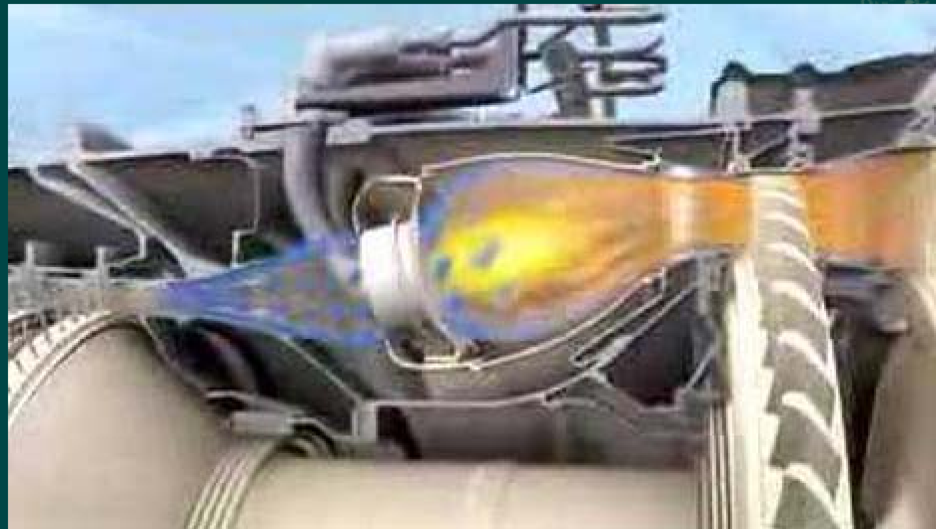


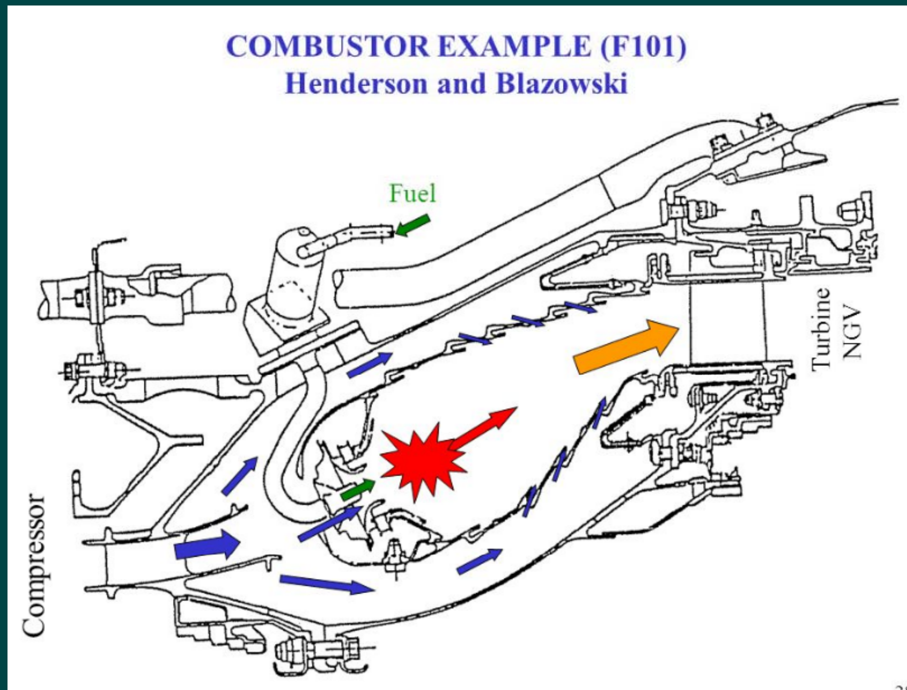
General scheme of coaxial jet disintegration.

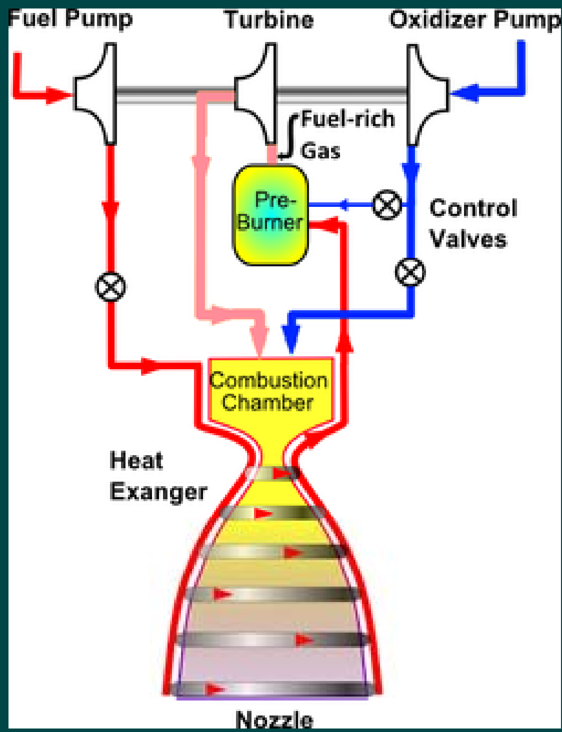





Concept
Motor
Coal Slurry
O2
sCO2
Impeller
Liner
Casing
Analysis
Design
Coal-water slurry feed
CO2 Feed
O2 Feed
Rotary Atomizer
Combustion zone
CO2 Feed
Inner liner




COMBUSTOR EXAMPLE (F101)
Henderson and Blazowski
Fuel
Turbine NGV
Compressor



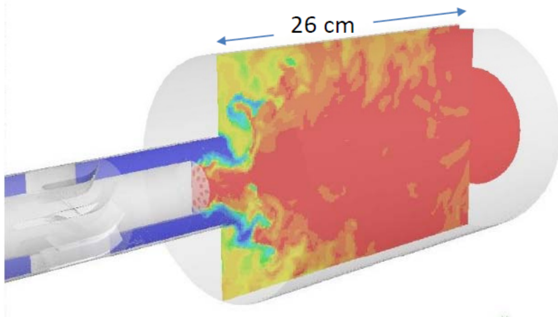
Liquid rocket engine (NASA 1963)

Oxy-Fuel Combustor Modeling

CFD exploration of high-pressure oxy combustion in a swirl stabilized non-premixed research combustor. What if???

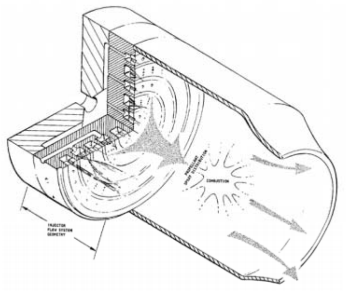
P=300bar
20%O2/80%CO2
T=2050K
Mdot=72 kg/s
180 MW

3.3M Cells
LES (Dynamic Smagorinsky)
1-step mechanism

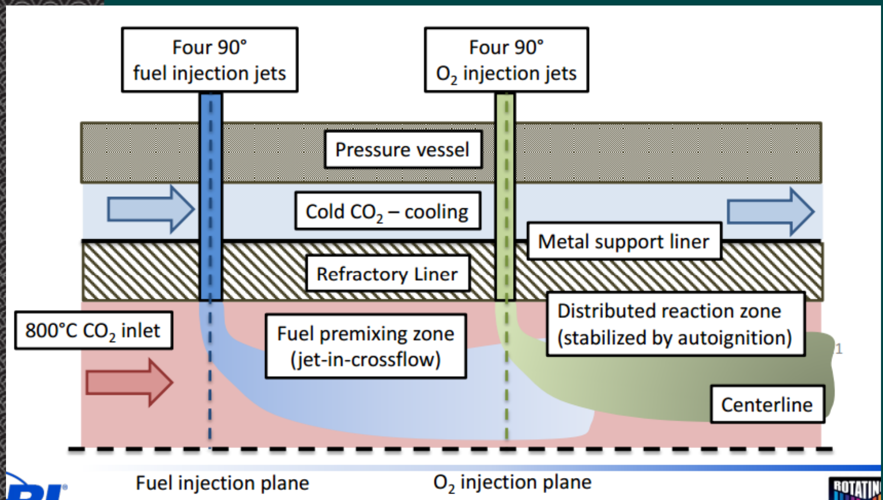


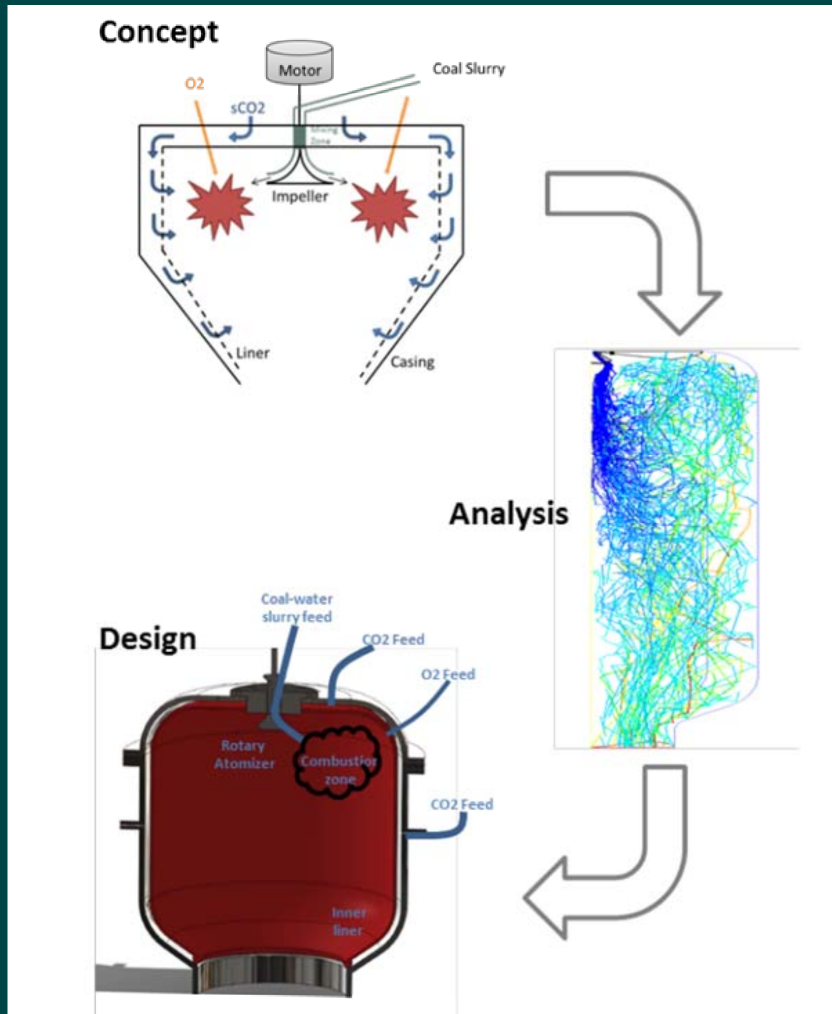
- Compressible LES formulation allows for simulation of combustion dynamics.

Oxy-Combustion



- Oxygen + reactant
- Direct fired sCO2 combustors have a third inert stream
- Challenge:
  - Mix and combustor fuel with out high temperature





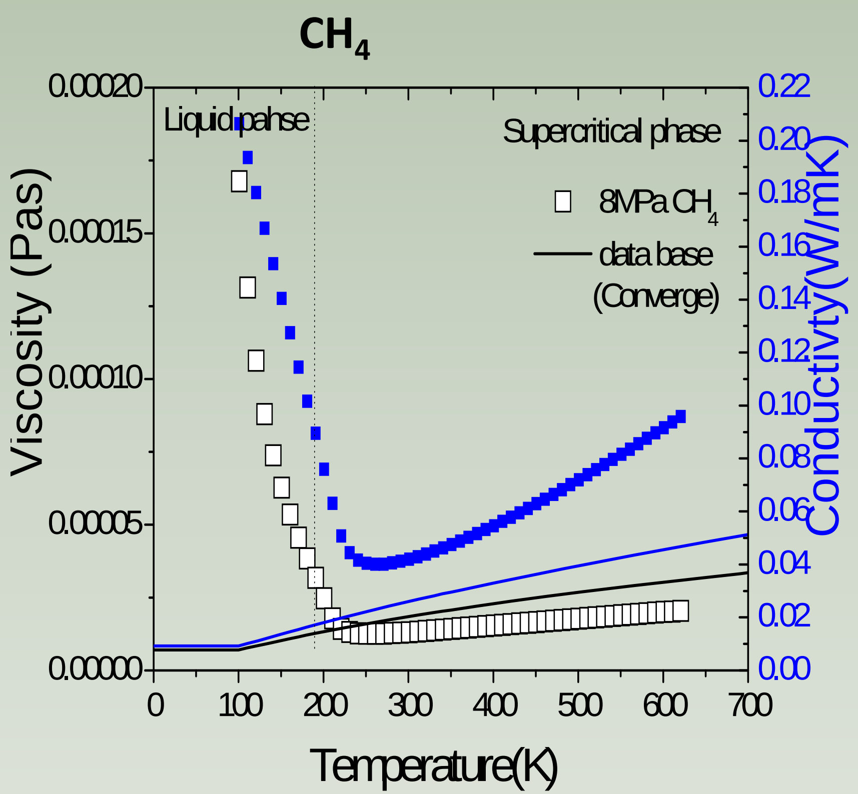
1. **Collect CH_4, CO_2, H_2O, O_2,CO, N_2 and H_2 Gas Properties**

- 利用"Thermophysical Properties of Fluid Systems– the NIST Webbook", 收集在相同壓力下(8MPa), CH_4,H_2,H_2O, CO_2,N_2, CO和O_2氣體,對溫度變化之Viscosity and Conductivity 數據並和逐一和Converge內建Gas property data base 數據做比對。

2. **Using "Converge" Scheme Simulate CO2 ,CH4 & O2 Combustion**

*Reference: J. Delimont, A. McClung, "Simulation of a Direct Fired Oxy-Fuel Combustor for sCO2 Power Cycles", SwRI, 2016.

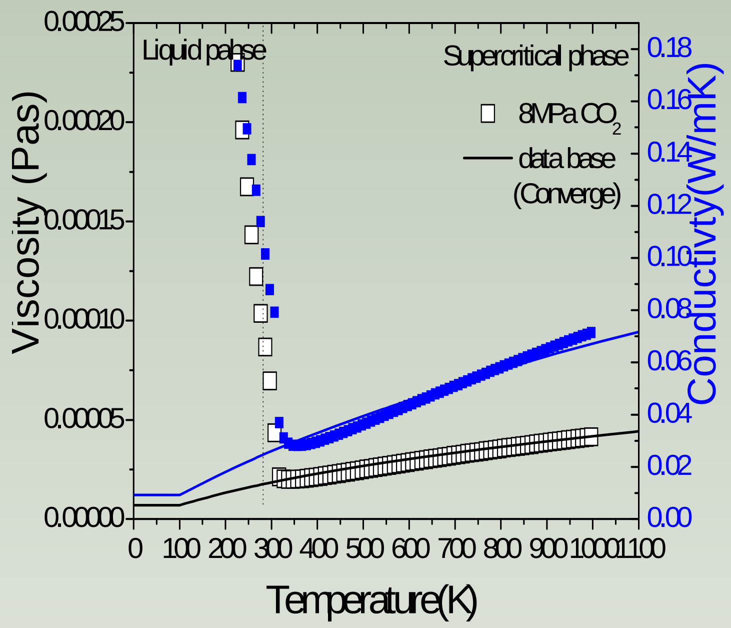
Task 1 Results: Gas property [CH_4 and species critical T and P]



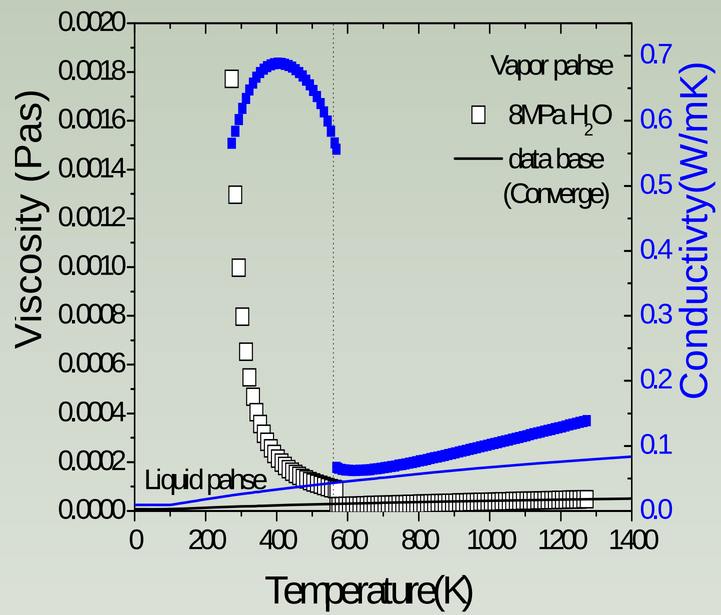
Species	T_c(K)	P_c(MPa)
CH_4	190.56	4.59
CO_2	304.12	7.38
H_2O	647.10	22.06
H_2	33.15	1.30
O_2	154.58	5.04
CO	132.86	3.50
N_2	126.19	3.40

Task 1 Results: Gas property [CO_2 and H_2O]

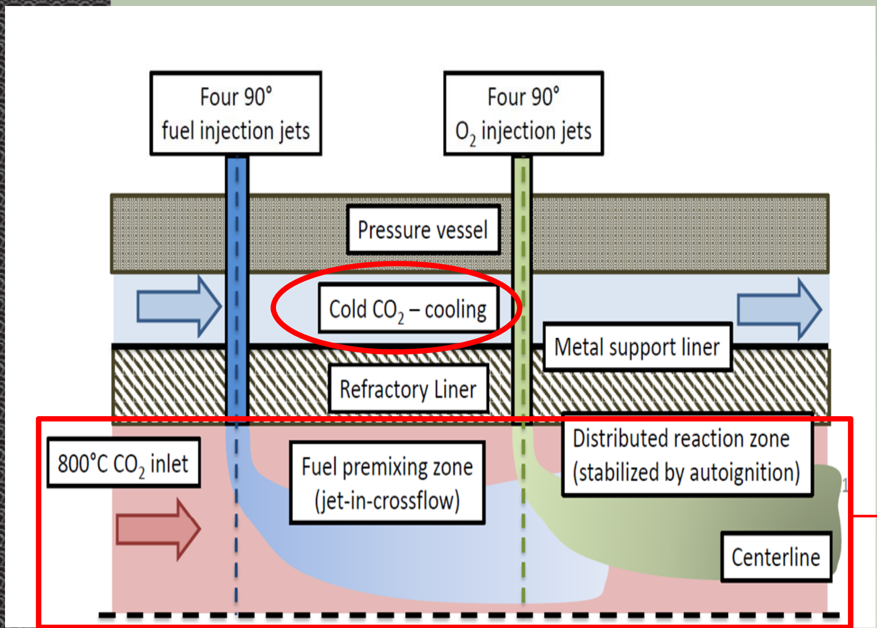
CO_2

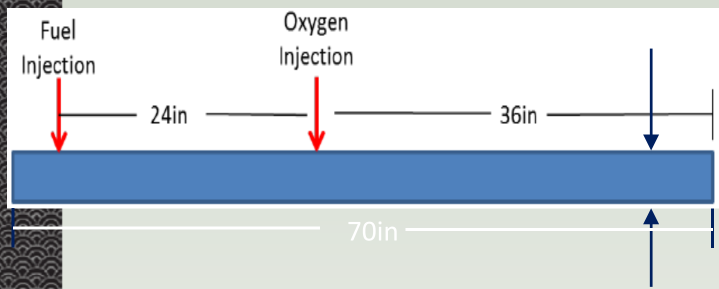


H_2O

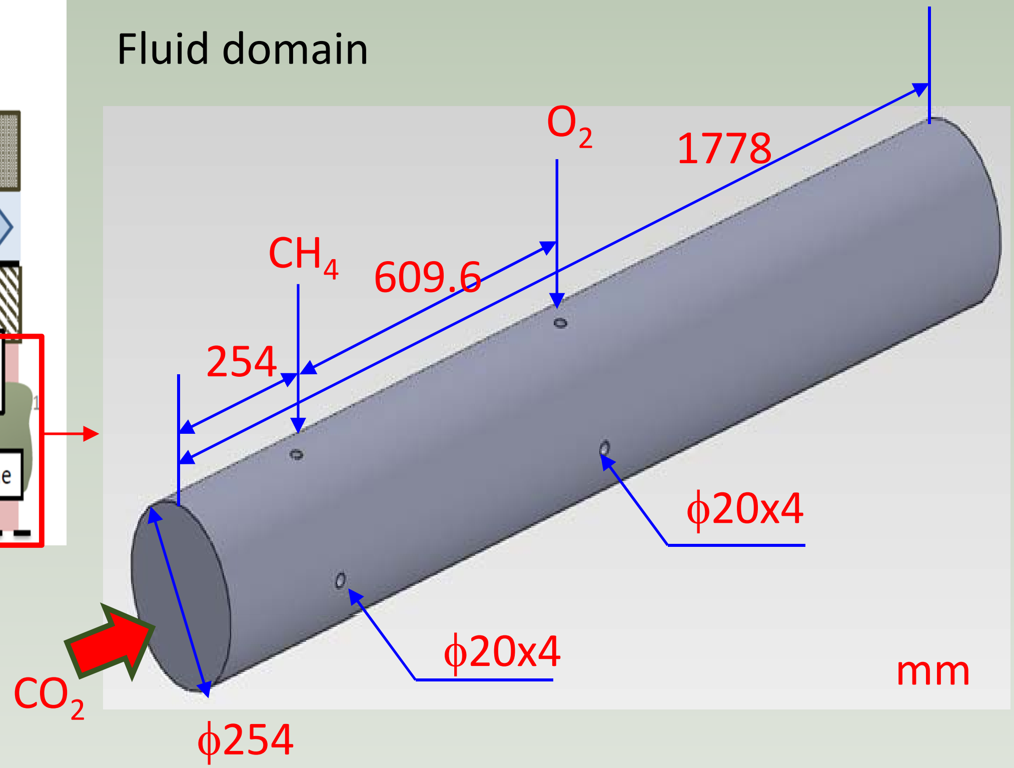


Computational domain





Fluid domain



Governing equation

- 質量守恆方程 $\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$

- 物種傳輸方程 $\frac{\partial \rho \phi_k}{\partial t} + \frac{\partial}{\partial x_i}\left(\rho u_i \phi_k - \Gamma_k \frac{\partial \phi_k}{\partial x_i}\right) = S_{\phi_k} \quad k = 1, \dots, N$

  Γ_k和S_{ϕ_k}為擴散係數和來源項。

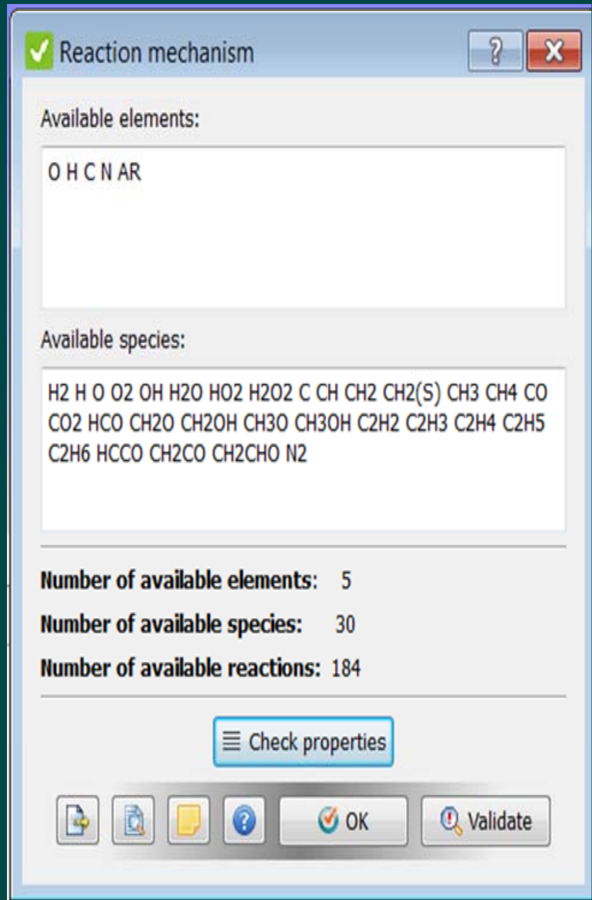
- 動量守恆方程 $\frac{\partial \rho}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = -\nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F}$

  $\bar{\bar{\tau}}$應力張量，$\bar{\bar{\tau}} = \mu\left[\left(\nabla\vec{v} + \nabla\vec{v}^T\right) - \frac{2}{3}\nabla \cdot \vec{v} I\right]$

- 能量守恆方程 $\frac{\partial}{\partial t}(\rho E) + \nabla \cdot \left(\vec{v}(\rho E + p)\right) = -\nabla \cdot \left(\sum_j h_j J_j\right) + S_h$

Combustion modeling: CEQ

- Simplify combustion modeling base on chemical equilibrium.
- When **chemical time-scales are faster than the fluid time-scales**, CEQ are used for the combustion modeling.
- The CEQ solver is ensure for any combination of gas species.
- This solver uses data in "***therm.dat***" and "*mech.dat*" to calculate the equilibrium concentration.
- We use the 30 species in Lu & Law's methane skeletal mechanism and thermodynamic data based on GRI 3.0 for this simulation.

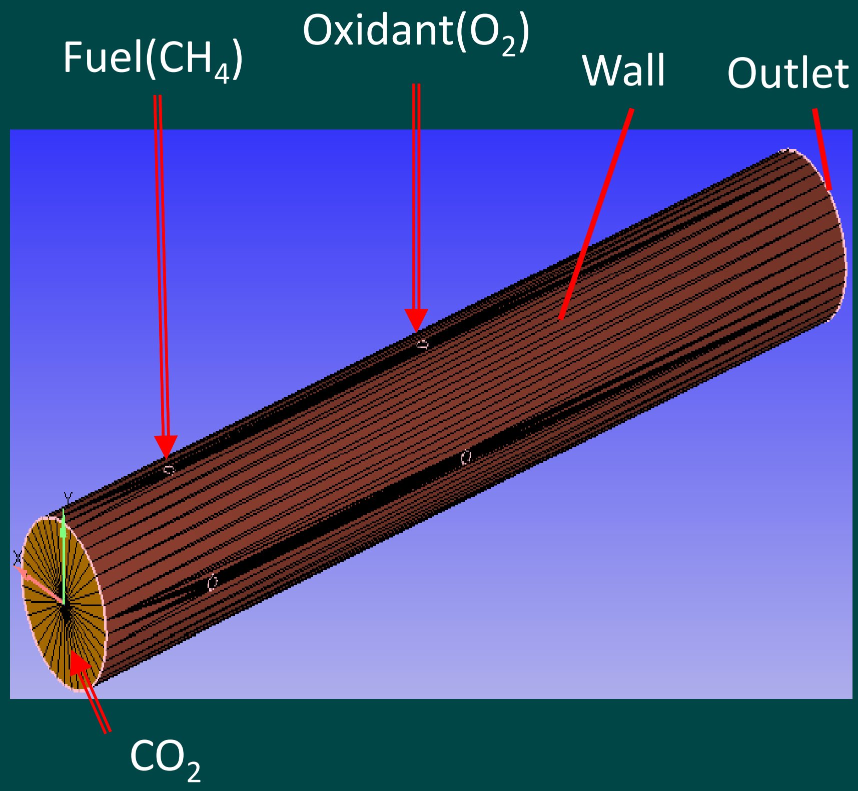


Reference:
Tianfeng Lu and Chung K. Law, "A criterion based on computational singular perturbation for the identification of quasi steady state species: A reduced mechanism for methane oxidation with NO chemistry," Combustion and Flame, Vol.154 No.4 pp.761–774, 2008.

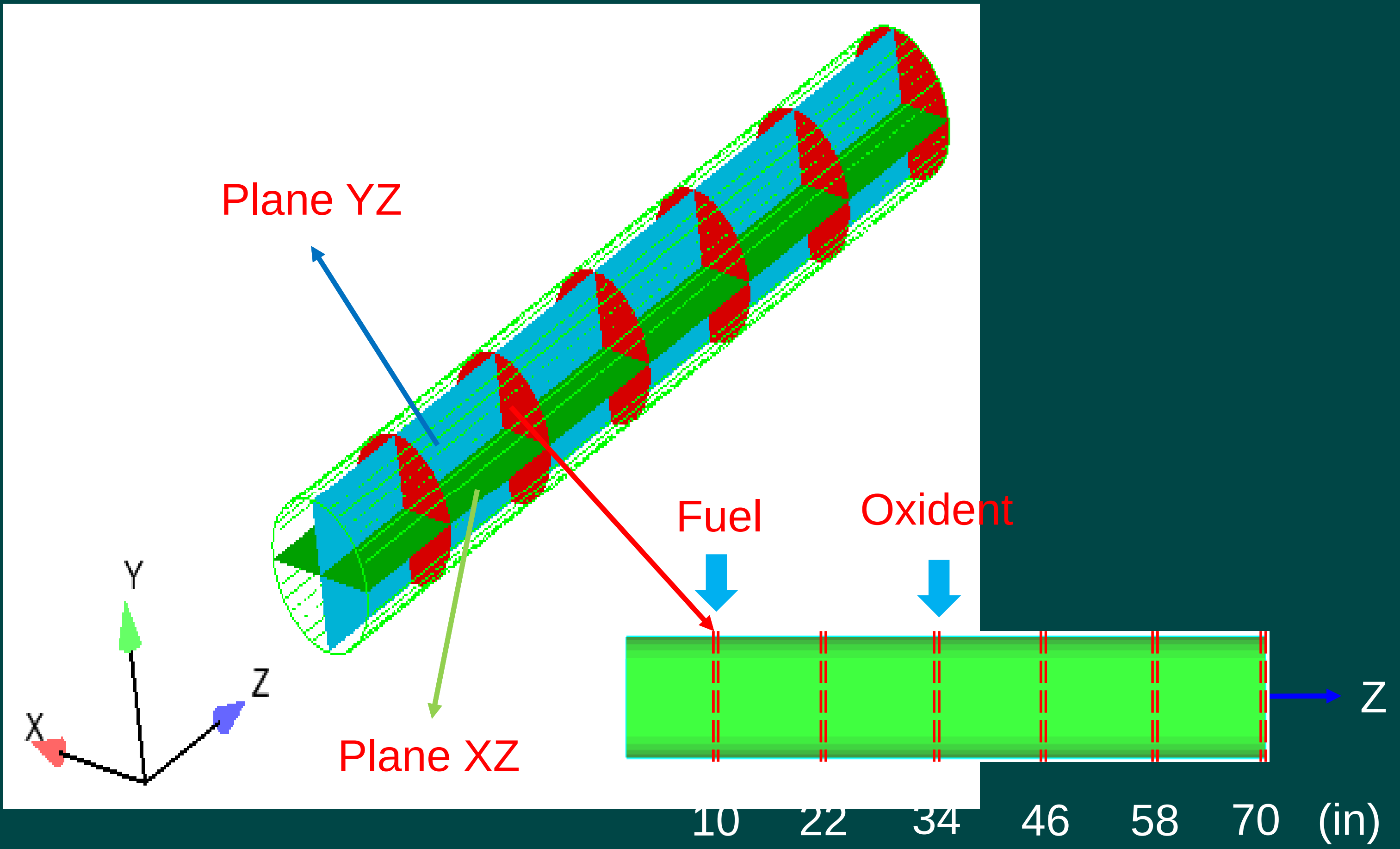
Boundary condition

Boundary ID	Type	Setting Parameter	Value	Unit
Fuel	INFLOW	velocity	10	m/s
		temperature	313	K
Oxygen	INFLOW	velocity	20	m/s
		temperature	313	K
CO_2	INFLOW	velocity	20	m/s
		temperature	1073	K
Outlet	OUTFLOW	pressure	7.4	MPa
Wall	WALL	temperature	313	K

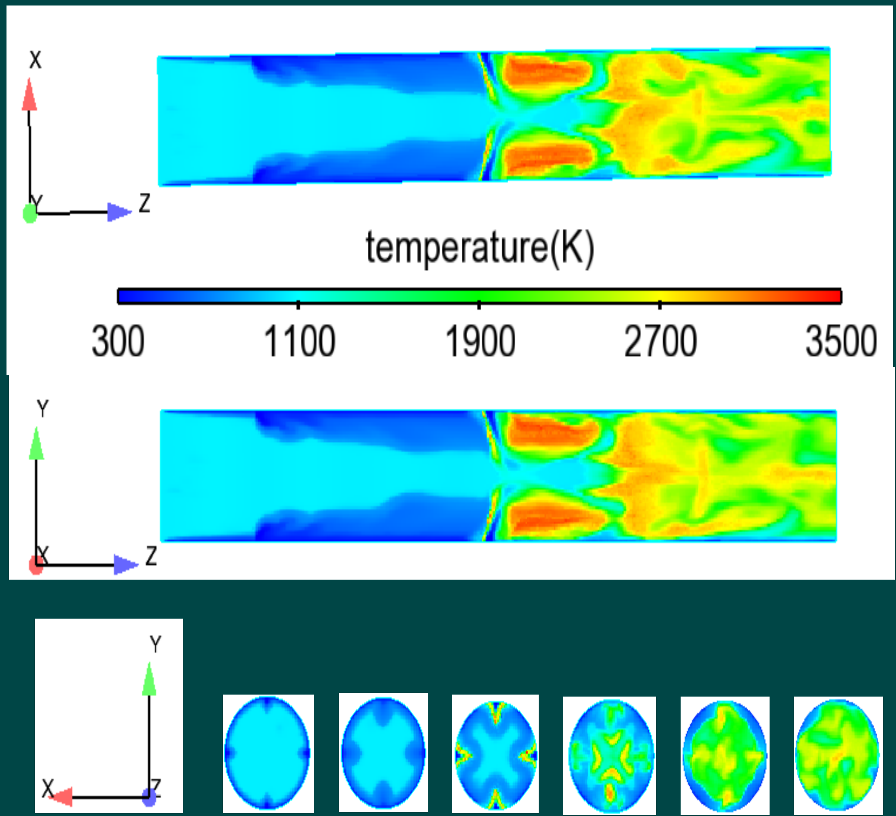
- 壁面設為313 K等溫邊界模擬Cold CO_2 cooling 的影響。
- 總釋熱率為33.55 MW。



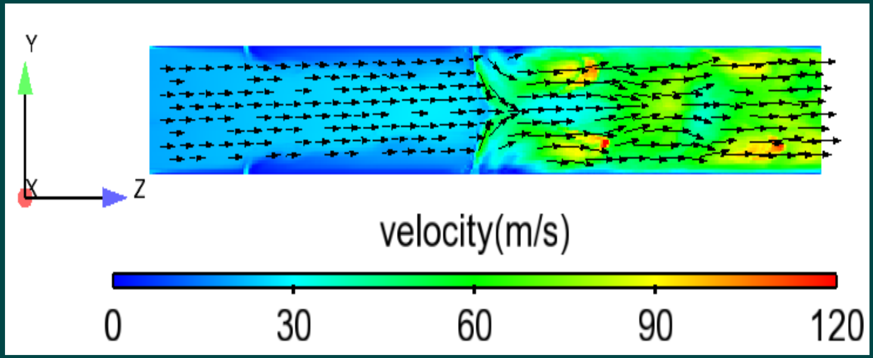
Observed Sectors Profile

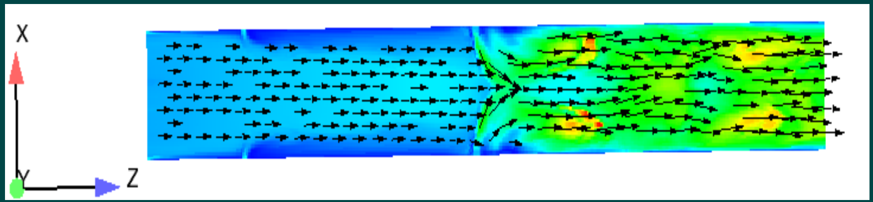


Results: Temperature (K)

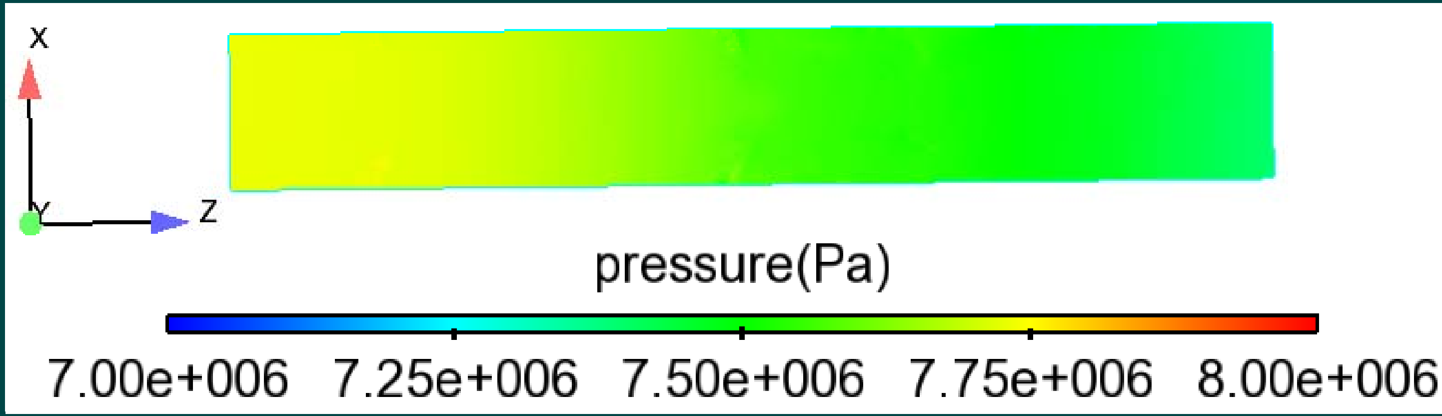


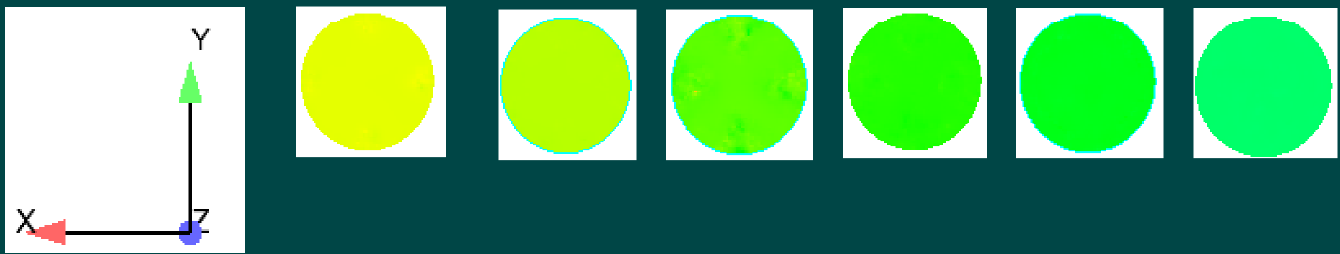
Results: Velocity Vector (m/s)



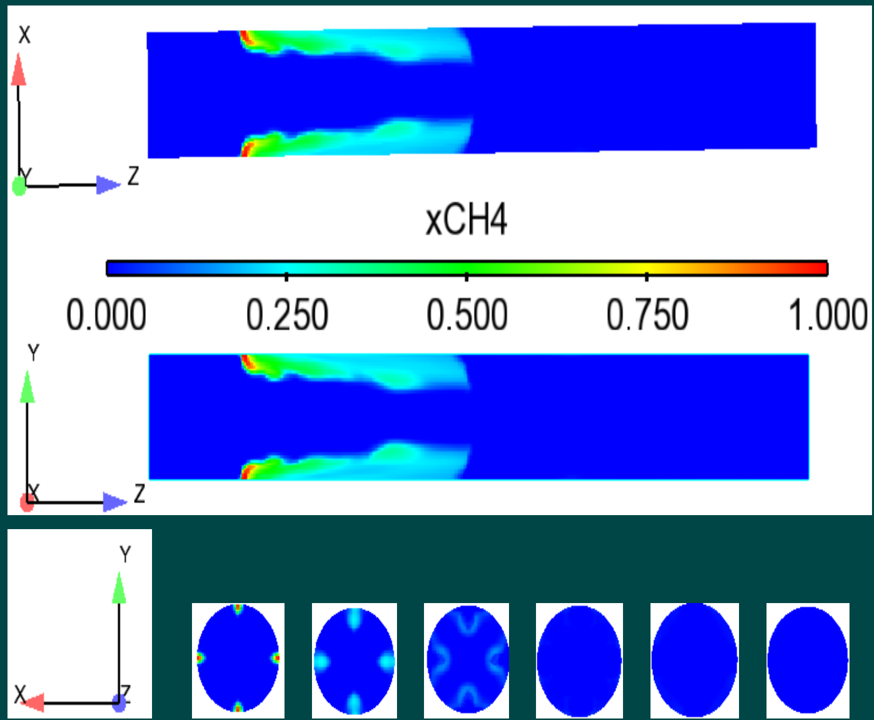


Task 2 Results: Pressure (Pa)

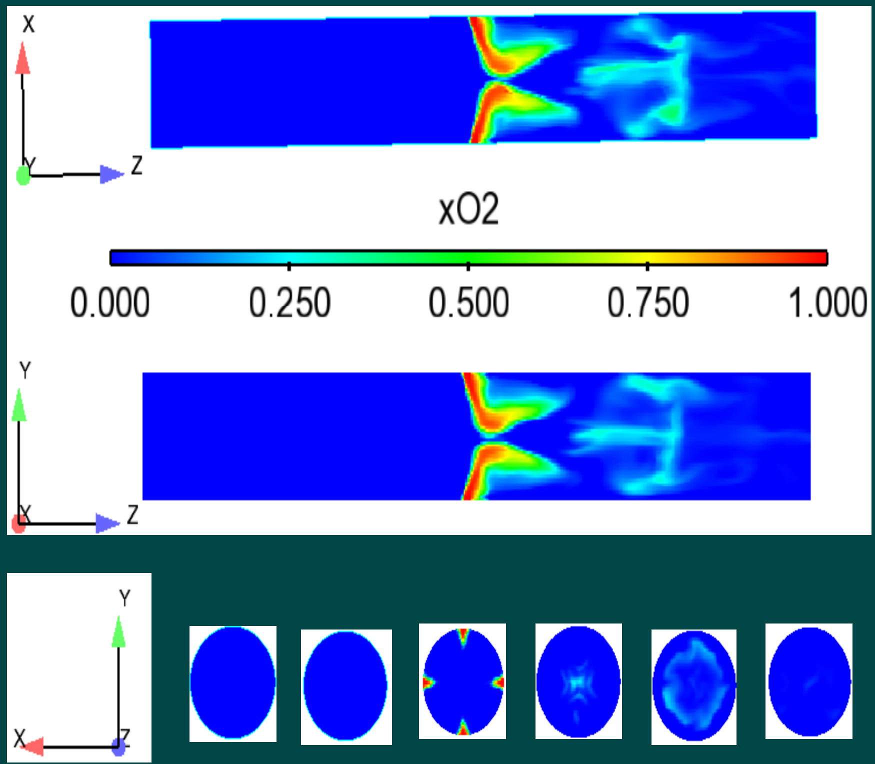




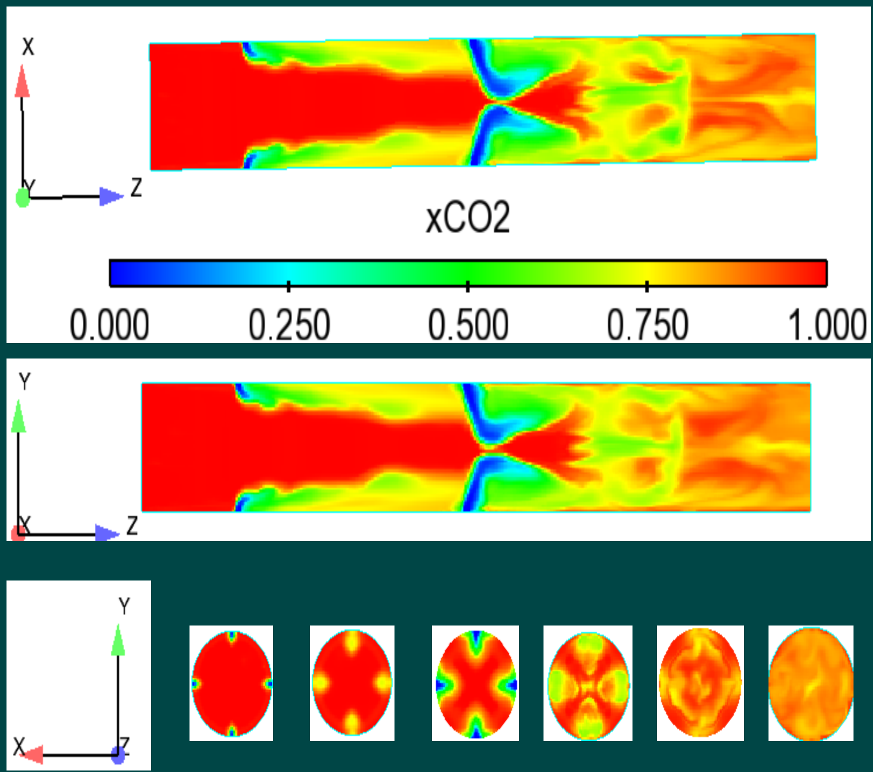
Task 2 Results: Mole fraction of CH_4



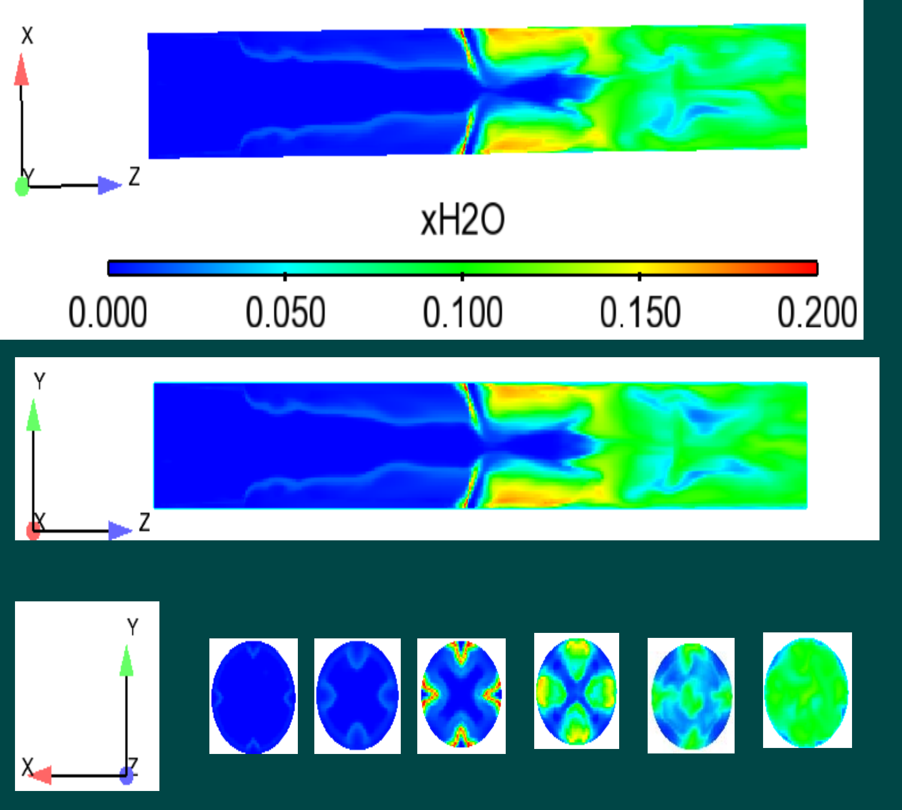
Task 2 Results: Mole fraction of O_2



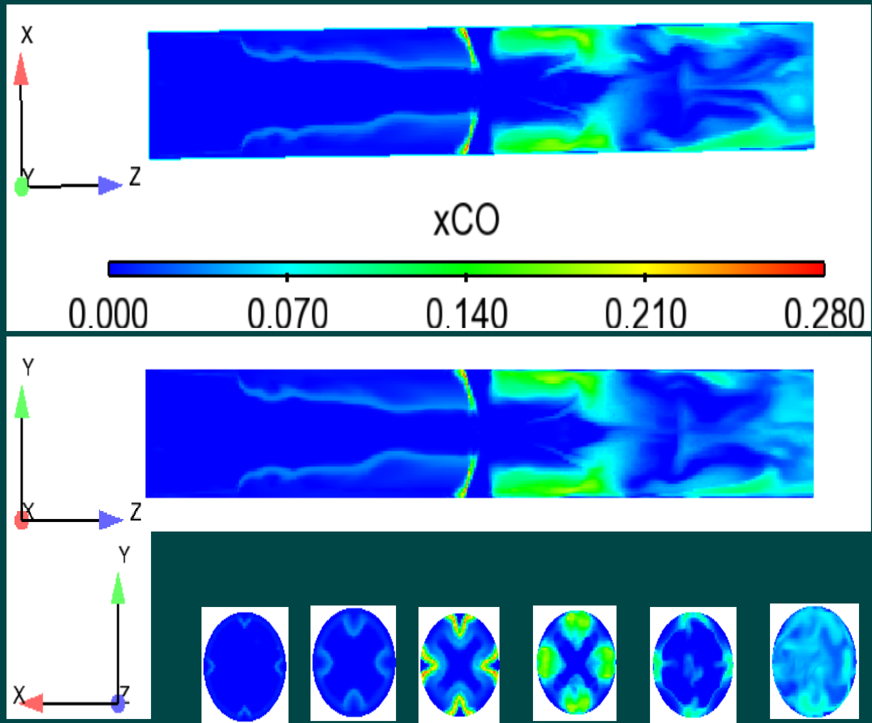
Task 2 Results: [Mole fraction of CO_2]



Task 2 Results: Mole fraction of H_2O



Task 2 Results: Mole fraction of CO



Task 2 Results: Exhausted Gas Compositions

Species	Percentage
xCO	4.98%
xCO2	85.59%
xH2	0.15%
XH2O	8.84%
xOH	0.07%
xO2	0.28%
xCH4	0.08%
Total	100%

Exhausted gas temp.: 1959K

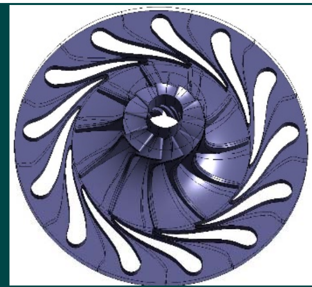
Future works

- TAC(Turbine-Alternator-Compressor) Designed, Coupled and Fabricated
- ISG will Establish Current Wave Feedback Control Mechanism , in Sine Wave Form Distribution
- SCO2 Thermal and Fluid System Integrate & Test。
- SCO2 Oxyfuel Combustor Parameters Analysis, including, locations and flow rate of injectors, wall temperature, exhaust gas composition, etc. Then fabricate and test.

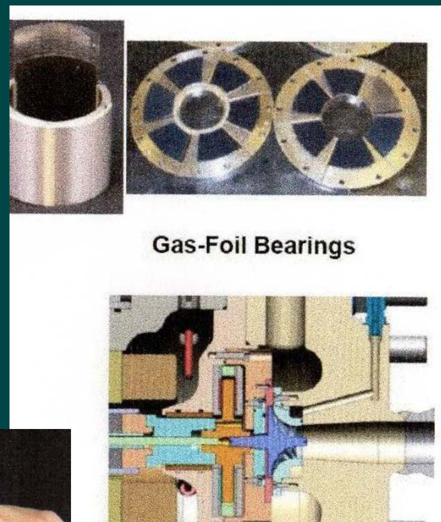
報告完畢
敬請指教

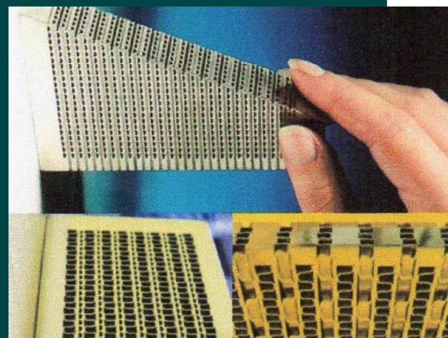
Thank You
For your Attention

重大執行困難



1. 如何再提升目前壓縮機(turbine)以及渦輪機(compressor)之等熵效率 (turbine > 90%, compressor > 85%)
2. 復熱器(Recuperator)之設計(能運作於 80bar <P <200 Bar 及 500˚C < T < 700˚C 之條件) 、效能及價格
3. 高溫材料(500˚C < T < 700˚C)之選擇
4. 次系統元件: 閥門及氣封、油封等
5. 系統在穩態(steady state)及動態(dynamic)下之運行
6. 系統整體之價格是否具競爭力





Milestones of the Project

重要成果

總計畫:

1. 完成熱力循環性能效率分析(ASPEN PLUS)
2. 純氧燃燒室的初步模擬設計(SwRI 文獻驗證)
3. 7/25 舉辦減碳淨煤國際研討會邀請Victor Der 及 Ting Wang 等keynote Speaker

子計畫一:

1. 完成渦輪轉子在設計點 1kg/s & 3kg/s質量流率、30000RPM 轉速下能提供 60%效率
2. 參加ASME及SCO_2會議收集關鍵設計資料

子計畫二:

1. 完成 ISG 發電機模式分析在額定轉速30000RPM 作功 10kW 下的初步性能
2. 改變永磁激磁方式，完成初步性能改善

子計畫三:

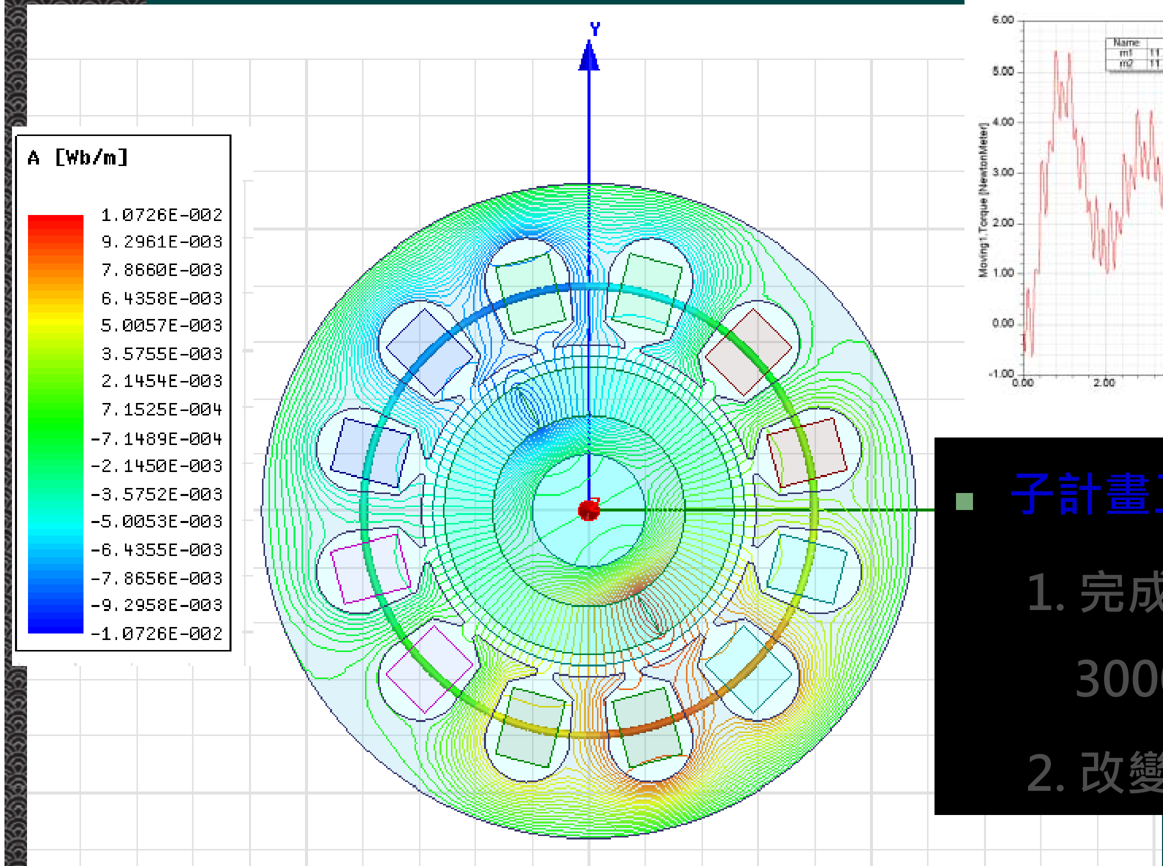
1. 以賈教授之SCO2熱發電雛型機進行優化
2. 完成 SCO2 全系統熱流分析、熱交換器設計及管路控制設計，並已委商製造

總計已有3篇國際論文發表以及申請專利一案(3件)

Comments & Suggestions

- 參照SWRI設計，完成一燃燒器建模，據以完成約33.55 MW之超臨界甲烷氧氣燃燒模擬。
- 由於combustor loading較大及所設定之壁面溫度過低，尾氣中有4.98%之CO，燃燒較不完全。
- 未來亦將探討燃料與氧化劑入口幾何與相對位置之影響，及提高壁面溫度至600 K以上，繼續模擬。

10kW Generator Design



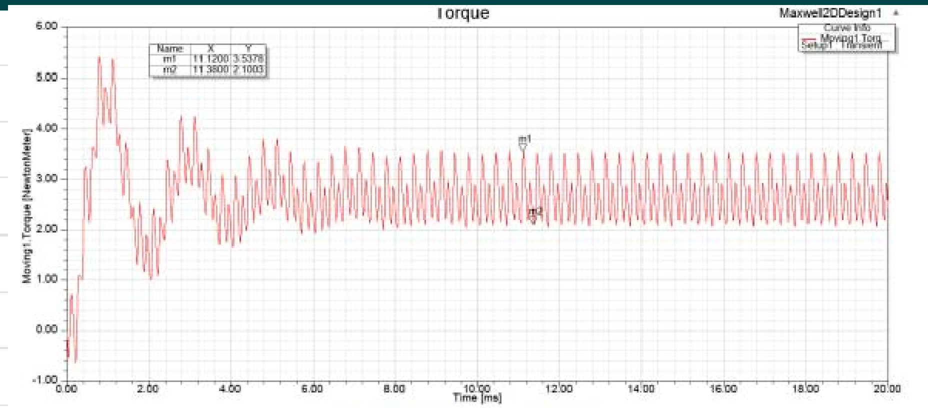


圖 6 發電機轉矩穩態分析

- 子計畫二:

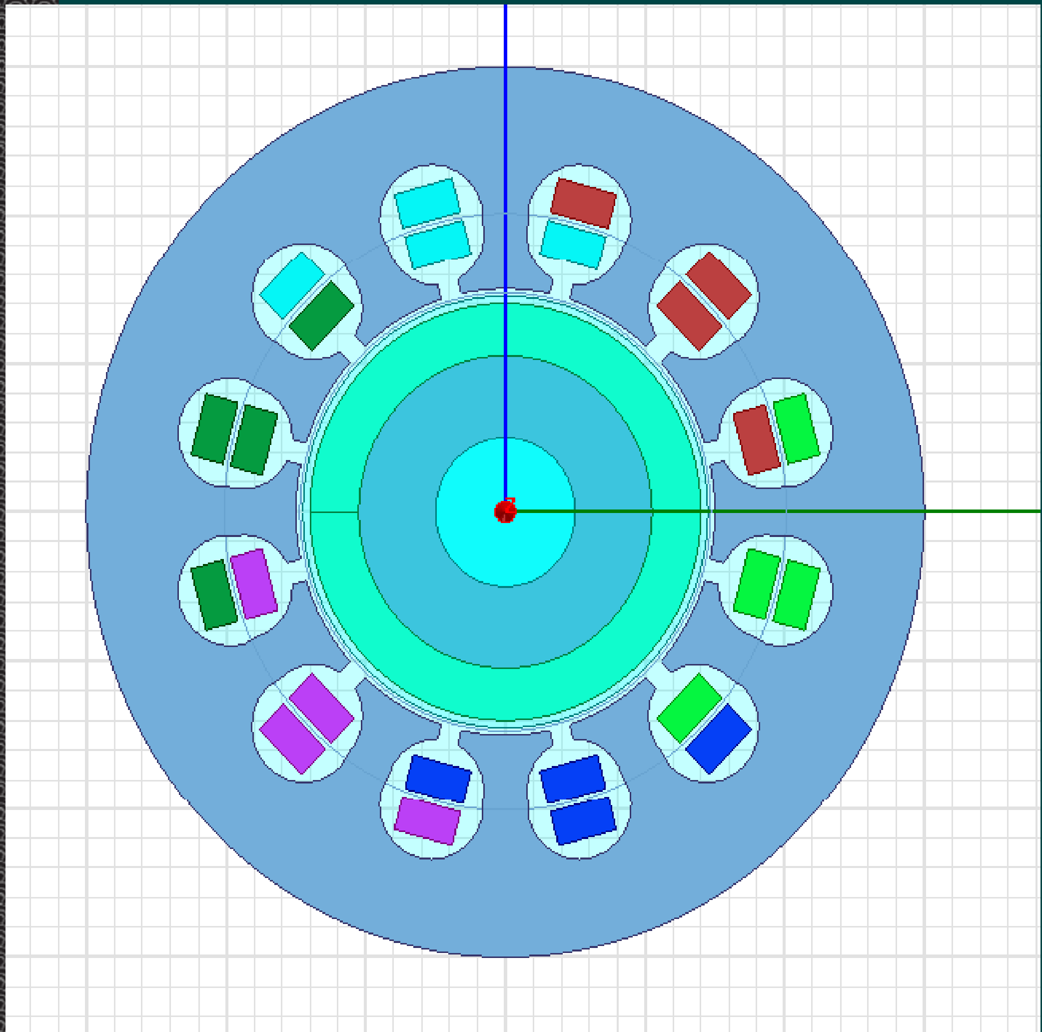
  1. 完成 ISG 發電機模式分析在額定轉速 30000RPM 作功 10kW 下的初步性能

  2. 改變永磁激磁方式，完成初步性能改善

10kW 永磁電動機規格

- 極與槽數 ： 2極12槽
- 額定功率 ： 10 kW
- 額定轉速 ： 30000 rpm
- 額定轉矩 ： 3.8 Nm
- 額定電壓 ： 220 V AC Volt 3 Phase

永磁電機尺寸細目



RMxprt 設 計 尺 寸	
馬 達 規 格	
極 數 (num)	2
槽 數 (num)	12
額 定 轉 速 (rpm)	25000
額 定 輸 出 功 率 (kW)	10
定 子 部 分	
定 子 外 徑 (mm)	60
定 子 內 徑 (mm)	30
定 子 長 度 (mm)	100
矽 鋼 片 材 質	35H250
轉 子 部 分	
轉 子 外 徑 (mm)	28
轉 子 內 徑 (mm)	10
轉 子 長 度 (mm)	100
矽 鋼 片 材 質	35H250
永 磁 部 分	
永 磁 厚 度 (mm)	3.5
永 磁 材 料	NdFeB_N34Z_140C

性能改善

- 電機高速旋轉下，因高次諧波影響嚴重，導致輸出轉矩之穩定性及三相輸出電流的弦波特性不良。

高次項諧波

穩態轉矩漣波

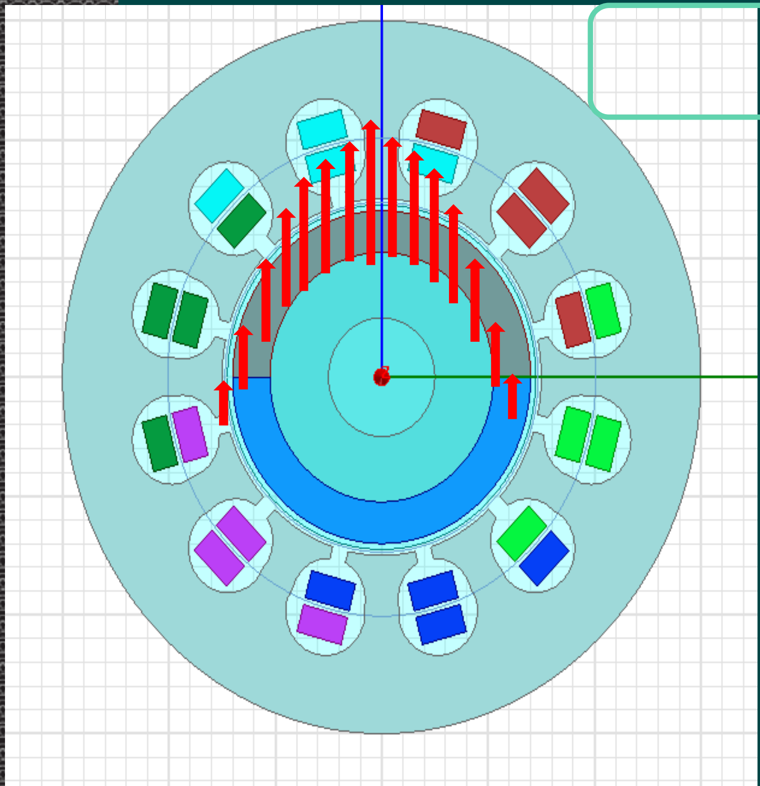
三相輸出電流

修改繞線方式：考慮弦波繞線

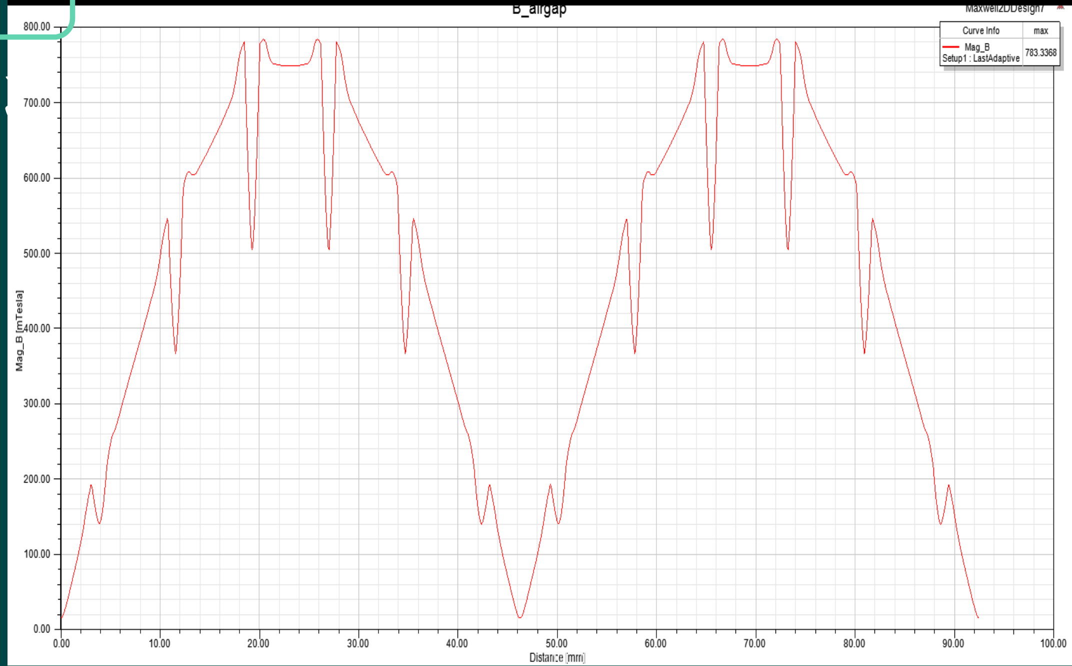
改變永磁激磁方式

改變斜槽

性能改善 – 改變永磁激磁方式

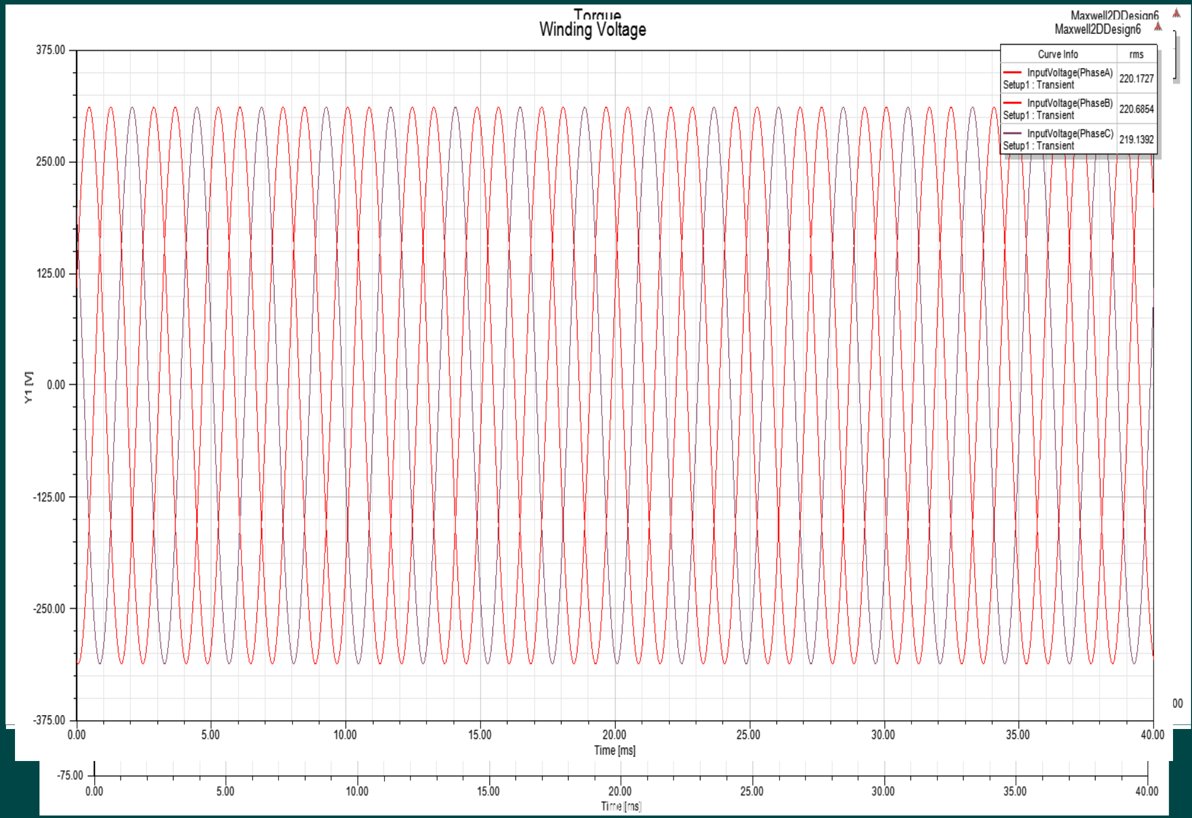


永磁在氣隙上的磁通分布



永磁電機之暫態分析

- 轉矩分布
- 三相電流分布
- 三相電壓分布



負載下三相電壓可達到額定電壓220 V