New Stirling Engine by Brayton Cycle without the dead volume problem fits for the Hydrogen Engine.

(KAIHO-Engine) (Patent (JPN 4520527) (JPN 6173080) (US 8,938,942 B2))

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Abstract

KAIHO-Engine is a kind of Stirling engine.

However, the principle and the configuration is quite different from the ordinary Stirling Engine.

The fundamental configuration of the KAIHO-Engine is a heater, a cooler, a regenerator and piston cylinders, connected by pipes separated by valves. KAIHO-Engine generates pressure difference between the heater and the cooler by a pure thermos-dynamical process. Using the piston cylinder and valves, it exchanges equal volume of hot working gas from the heater with cool working gas from the cooler and generates the mass flow from the cooler to the heater, by the difference of density and generates the pressure difference between the cooler and the heater. The pressure in the heater is always high and the pressure in the cooler is always low. KAIHO-Engine generates power by this pressure difference between the heater and the cooler.

Theoretically, there is no restriction for the size of the heater, the cooler, the regenerator nor the piping for these process.

KAIHO-Engine has these merits.

- Free from the dead volume problem.
- Practically Brayton Cycle. .
- The flow of the working gas is one directional and one set of a heater, cooler and regenerator can be used by plural number of engines (Multi KAIHO-Engine).
- At multi KAIHO-Engine, generated power is continuous and smooth and high power is possible.
- The flow of the working gas through the heater or the cooler is continuous and smooth. The heater and the cooler is working all through the cycle under almost constant condition.
- Controlled by valves. Using electric valves, KAIHO-Engine can be remotely controlled.
- Do not need He gas for the working gas . Ar gas or N_2 gas can be used with high efficiency.
- The pressure ratio can be easily over 2 for ordinary purpose and near 3 for special purpose.
- Simple structure. Main parts of the engine (Valve blocks, Piston blocks) are only holed blocks. Ceramic might be able to be used with good results.
- Especially fits for the Hydrogen Engine. Hydrogen fuel produce no burnt residue while KAIHO-Engine has little combustion problem since it is an outer combustion engine.

Index (List of Notations)

List of Notations and the Proposed Case

				Proposed Case
Temperature of the working gas		T_H	High (at the exit of the Heater)	･･･ K
		T_L	Low (at the exit of the Cooler)	320K(47℃)
Pressureof the working gas		P_H	HIgh (in the Heater)	･･･ MPa
		P_L	Low (in the Cooler)	2MPa
		P_X	Under the piston of the Piston Cylinder	･･･ MPa
		P_Y	Above the piston of the Expansion Cylinder	･･･ MPa
Piston	Area	S	Piston Cylinder	78.5cm^2
		S_E	Expansion Cylinder	･･･ cm^2
	Diameter	ϕ	Piston Cylinder	10cm
		ϕ_E	Expansion Cylinder	･･･ cm
	Stroke	St	Stroke (Common)	10cm
DIsplacement		V	Piston Cylinder	785.cm^3
		V_P	Power Piston Cylinder	･･･ cm^3
		V_E	Expansion Cylinder	･･･ cm^3
Revoltional Speed			(Common)	10rps

1 Summary

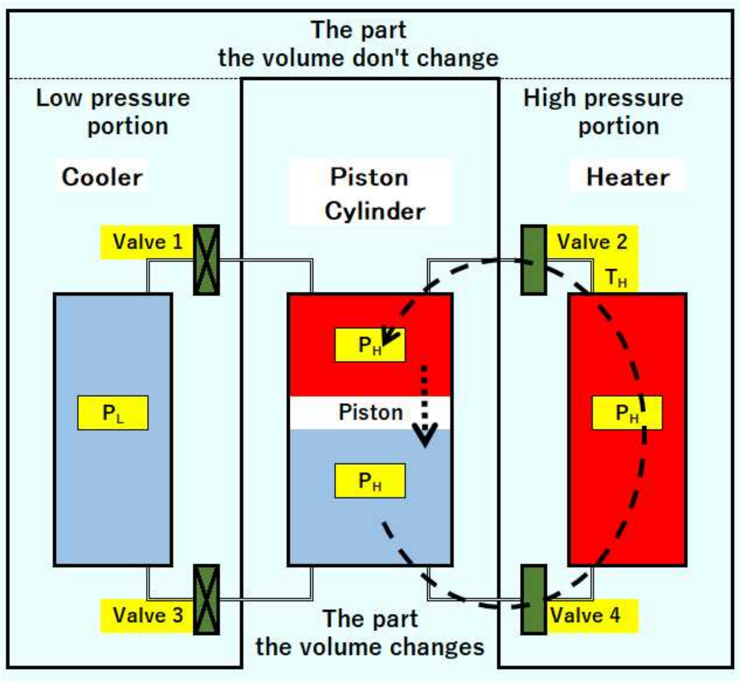


Fig1-1 The fundamental configuration of the KAIHO-Engine

KAIHO-Engine is an external combustion closed cycle engine without the phase change of the working gas and is a kind of Stirling Engine, but the principle and the configuration of its is quite different from the ordinary Stirling engine.

The fundamental configuration of the KAIHO-Engine is a heater, a cooler, a regenerator and piston cylinders, connected by pipes separated by valves (Fig1-1).

KAIHO-Engine generates the pressure difference between the heater and the cooler by a pure thermos-dynamical process. Using the piston cylinder and valves, it exchanges equal volume of hot working gas from the heater with cool working gas from the cooler and generates the mass flow from the cooler to the heater, by the difference of density and generates the pressure difference between the cooler and the heater.

This process goes until the density of the hot gas from the heater and the cool gas from the cooler become equal.

$P_H/P_L = T_H/T_L$ by the Boyle Charles' law.

The pressure ratio, P_H/P_L can be easily over 2 for ordinary purpose, near 3 for special purpose, significantly larger than the usual Stirling engine.

The pressure in the heater is always high and the pressure in the cooler is always low.

Theoretically, the size of the heater, cooler, regenerator nor piping has no relation to these processes including power generation process . KAIHO-Engine is free from the dead volume problem.

KAIHO-Engine generates power by this pressure difference between the heater and the cooler. It is possible to use the power piston to generate the power, but it is better to use the adiabatic process within the thermal cycle of the KAIHO-Engine.

KAIHO-Engine can be separated to two parts, the part the volume of which do not change and the part which changes (the displacement of the piston cylinders). The part the volume of which do not change is consisted of the high-pressure portion: the heater, high pressure portion of the regenerator and the piping, plus the buffer tank if needed, and the low-pressure portion: the cooler, low pressure portion of the regenerator and the piping, plus the buffer tank if needed(Fig1-1).

The volume of the part which does not change is much larger than the part which changes and the pressure change is significantly small (below 0.3% for the proposed case). For practical purpose, P_H, and P_L are constant and is Brayton Cycle (will be discussed later).

The flow of the working gas of the KAIHO-Engine is one directional and one set of heater, regenerator and cooler can be used by plural number of engines (multi KAIHO-Engine), so the power generated is continuous and smooth.

The flow of the working gas through the heater or cooler is continuous and smooth. The heater and the cooler is working all through the cycle under almost constant condition.

A KAIHO-Engine (2012 Model), two units of engines combined and using one set of heater, regenerator and cooler, was built and tested by the assistance of NEDO. The results showed good agreement with the theory and it was confirmed that the KAIHO-Engine is free from the restriction of the dead space problem, no restriction for the size of the heater and the cooler, nor the piping.

Only serious problem was the valve which was solved by the development of a new type of valve. (Floating valve-seat type poppet valve).

Theoretical performances of the KAIHO-Engine and the effect of the working gas for the proposed case was calculated by the assumption of Brayton cycle and is shown in Fig1-2.

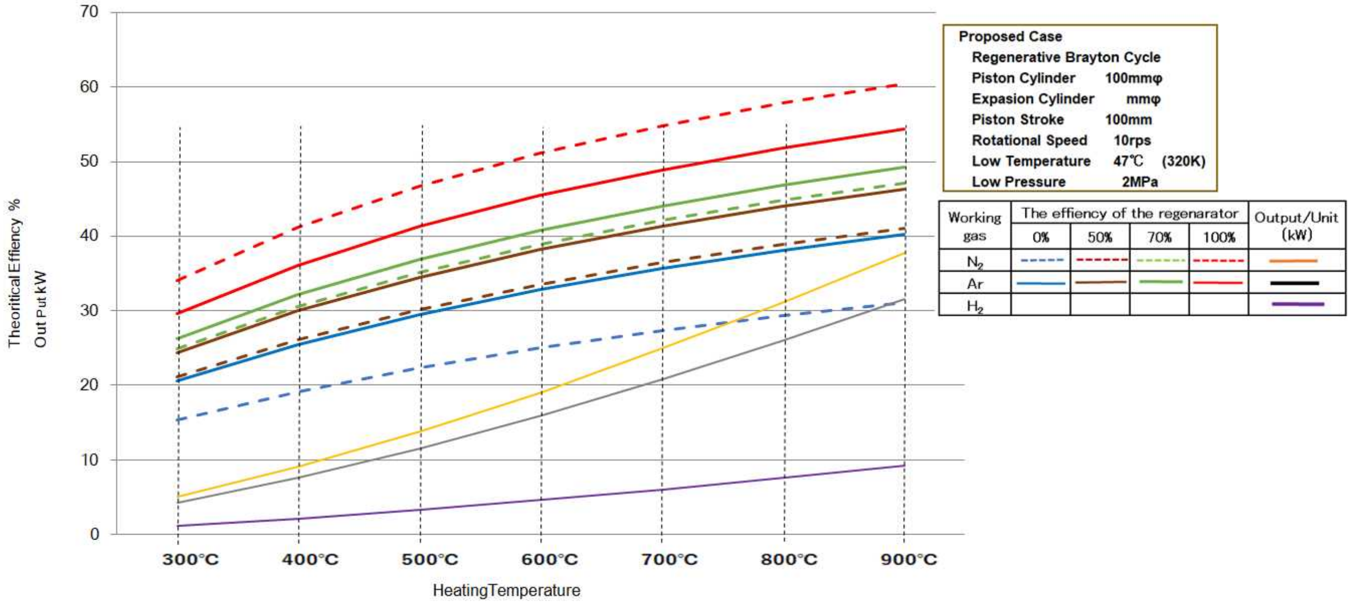


Fig 1-2 Theoretical performances of KAIHO-Engine and the effect of the working gas for the proposed case

2 The principle of KAIHO-Engine

The KAIHO-Engine generates the mass flow of the working gas from the cooler to the heater by exchanging equal volume of hot working gas from the heater with cool working gas from the cooler using the piston cylinder and valves. This process goes until the density of the hot gas from the heater and the cool gas from the cooler become equal. $P_H/P_L = T_H/T_L$ by the Boyle Charles' law.

This process is shown in Fig2, goes from A to B, C, D and returns to A, repeating.

The pressure ratio, P_H/P_L can be easily over 2 for ordinary purpose, near 3 for special purpose, significantly larger than the usual Stirling engine.

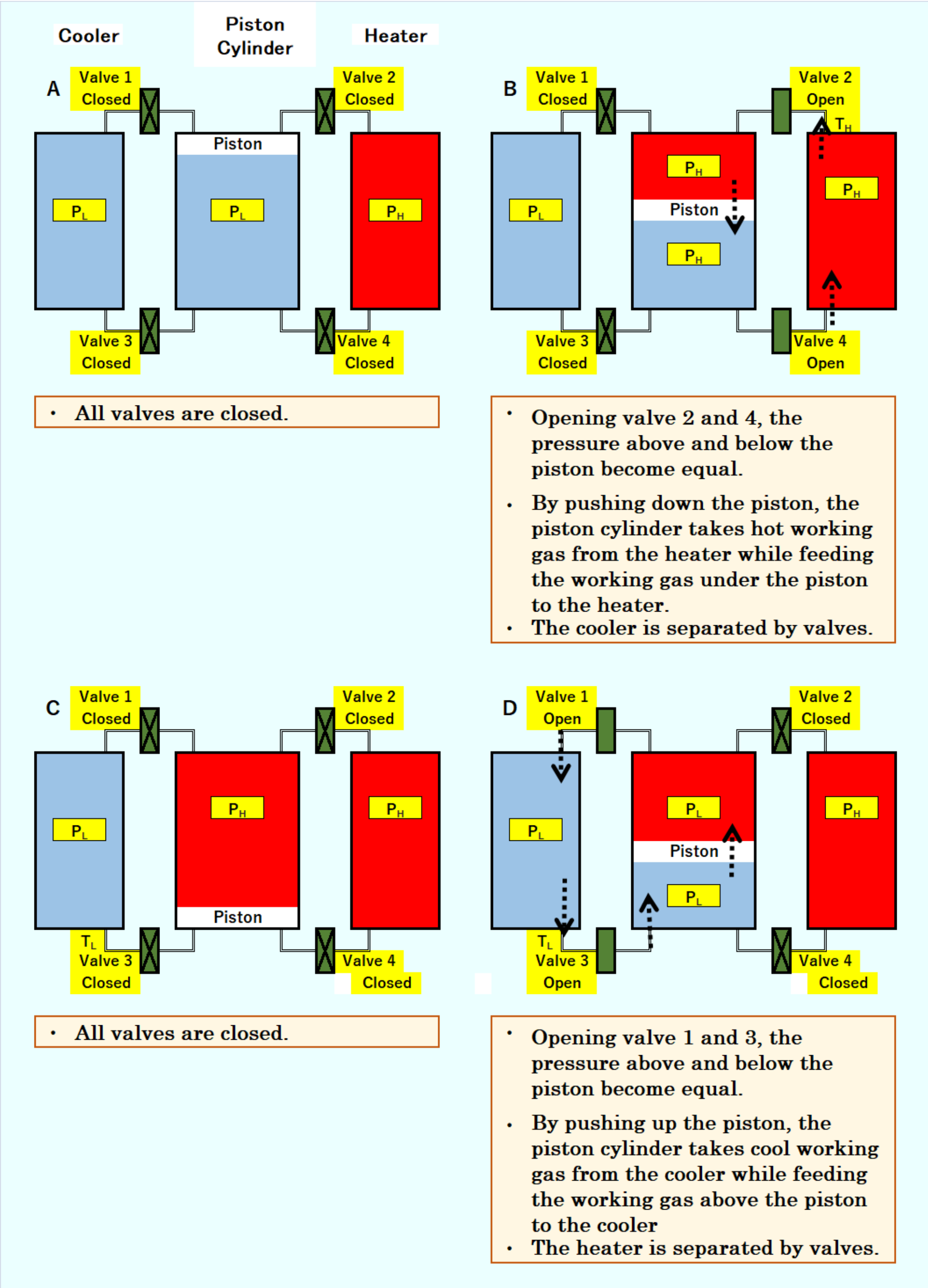


Fig 2 Principle of the KAIHO-Engine

3 Power generation by the adiabatic process

The KAIHO-Engine generates power by this pressure difference between the heater and the cooler. It is possible to use power piston to generate the power, but it is better to use the Adiabatic Process within the thermal cycle of the KAIHO-Engine.

The stage Fig 2-B, can be modified for the power generation by the adiabatic compression process to Fig3-A to B, and the stage Fig 2-D can be modified for the power generation by the adiabatic expansionv process to Fig3-C to D.

The configuration for the power generation by the adiabatic process is shown at the Fig 3. In Fig 3, the expansion cylinder was added to the system .

In Fig 2-B, the valve 2 and 4 is open, so that there is no pressure difference across the piston. No power generates.

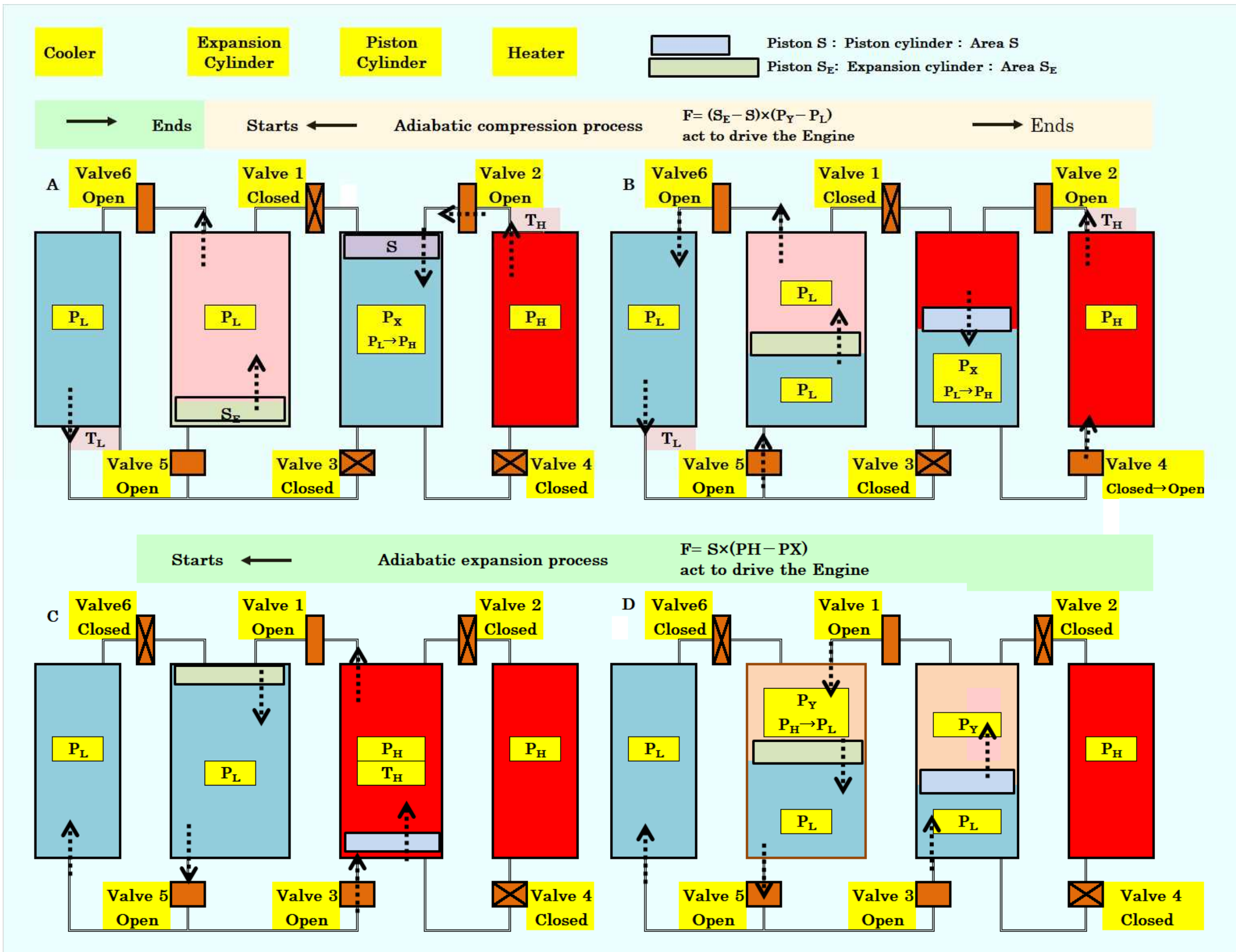


Fig 3 Power generation by the Adiabatic Process

In Fig 3-A, the valve 4 is closed, so that the working gas under the piston is trapped, while the pressure above the piston is high P_H. The piston is pushed down with the force $S\times(P_H-P_X)$ and generates the power. The working gas under the piston is compressed adiabatically and its pressure P_X increase. In Fig 3-B, P_X became P_H, and at this point the valve 4 is opened and after that no power generates.

In Fig 2-D the valve 1 and 3 are open, so that there is no pressure difference across the piston. No power generates.

In Fig 3, the piston of the expansion cylinder (S_E) is connected to the piston of the piston cylinder (S) by the crank system.

In Fig 3-C, valve 1 is open, Valve 6 and 2 are closed. The working gas between the pistons is combined and trapped. The piston S get the force $S\times(P_Y-P_L)$ and S_E does $S_E\times(P_Y-P_L)$. In total, $F=(S_E-S)\times(P_Y-P_L)$ drives the engine and generates the power. The displacement of the expansion cylinder was set equal to the volume of the high pressure (P_H) and high temperature (T_H) working gas in the piston cylinder expanded adiabatically to low pressure P_L. The trapped gas expands adiabatically, and the pressure P_Y changes from P_H in Fig 3-C to P_L at Fig 3-A.

4 The 2012 Model KAIHO-Engine

A KAIHO-Engine (2012 Model) was built and tested by the assistance of NEDO. The configuration of it is shown in Fig4-1. It had worked, though, delayed by many troubles common to the entirely new system.

The picture of its is shown in Fig 4-2. Big diameter piping and a N_2 gas bombe for the working gas should be noticed.

Two unit of the engine combined shared one set of the heater, cooler and regenerator without trouble.

The resulting pressure difference showed good agreement with the theory. It was confirmed that the KAIHO-Engine works and is free from the restriction of the dead space problem, no restriction for the size of the heater and the cooler, nor the piping.

N_2 gas was used as the working gas and caused no trouble. Also, the carbon piston ring worked well.

Only serious problem was the valve.

The troubles of the valves had restricted the rotational speed and the pressure difference to about 1/3 of the plan, and the output remained about 1/10 of the plan.

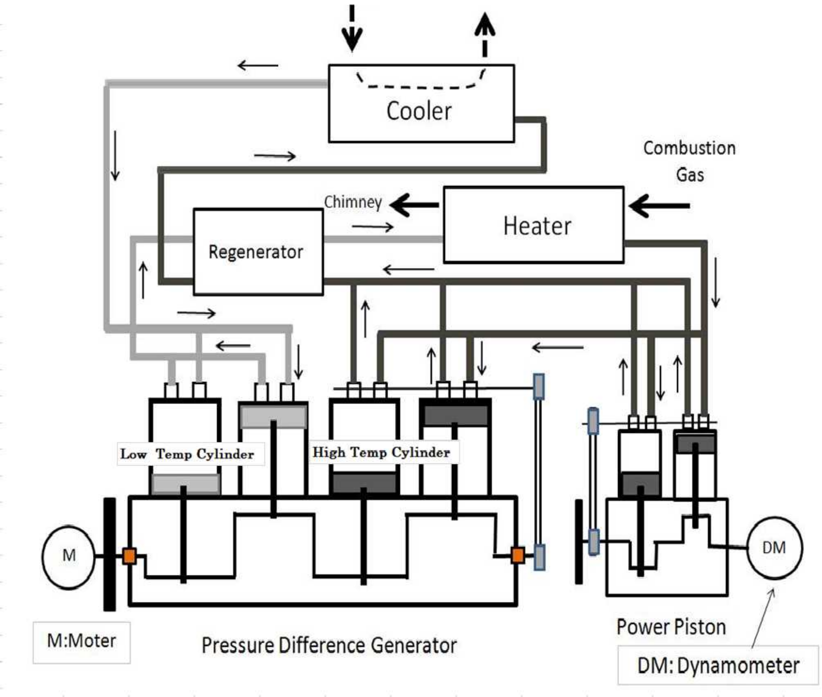


Fig 4-1 Configuration of the 2012 model KAIHO-Engine

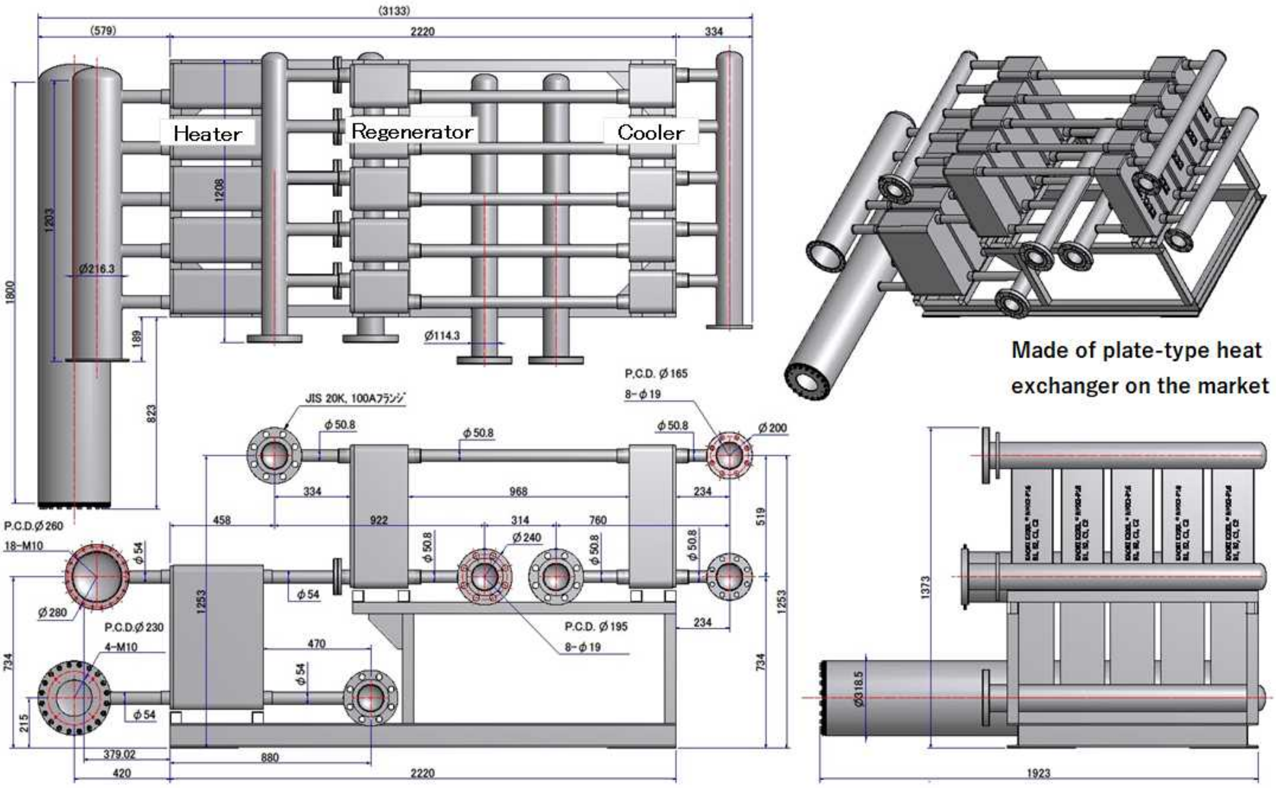
Fig 4-2 The 2012 Model KAIHO-Engine

Fig 4-3 The Heater, the Cooler and the Regenerator system

Table 4-1 Spec of the 2012 Model KAIHO-ENGINE：Built by the Aid from NEDO

Power piston type：PH／PL = (TH／TL)×(V − VP)／V			
Working Gas	N2		
Power Generator	Power Piston	120mmφ×120mm×2 (Vp =1.36L×2)	Exhaust Valves：Popet Type, 40mmφ * 2 /each cylinder Intake Valves： Popet Type, 40mmφ * 2 /each cylinder
Pressure Difference Generator	High Temperature Cylinder	180mmφ×180mm×2 (V =4.58L×2)	Exhaust Valves：Popet Type, 40mmφ * 2 /each cylinder Intake Valves： Popet Type, 40mmφ * 2 /each cylinder
	Low Temperature Cylinder	180mmφ×180mm×2 (V =4.58L×2)	Exhaust Valves：Non Return Type, 40mmφ * 2 /each cylinder Intake Valves： Non Return Type, 40mmφ * 2 /each cylinder Non Return Valve is used since it opens automatically by the pressurec ondition in the cycle
			Generate Power by Adiabatic Compression
Heater	Plate Type		
Cooler			
Regenerator			
Heat Source	Gas Burner		
Piston Seal	Carbon Piston Ring		
OutPut (Planned)	23kW (at the condition P_L = 2MPa、T_H = 300℃, T_L = 50℃ → Pressure Difference = 1.6MPa, n = 10rps)		

Fig 4-4 The Heater, the Cooler and the Regenerator system of the 2012 Model KAIHO-ENGINE



The valve of 40mmφ needs about 200kgf of force to open against the pressure difference of 1.6MPa planned. Some measure (pressure balanced valve and others) were taken, but it was not enough. The pressure difference was limited.

The rate of pressure decreases after the valve opened was found too slow, because the poppet valve takes time to open fully. Thus, the rotational speed was limited.

The non-return valves fitted to the low temperature cylinder to open automatically when the piston began to descend and the pressure above the piston decrease had worked. However, the valve delayed shortly to open by the inertia of the valve head. It caused too much decrement of the pressure and caused the force to stop the rotation. It was forced to rotate by the flywheel and the starter motor but caused strong shock and finally broken the crankshaft, by fatigue fracture.

This valve problem was solved by the development of a new type of the valve (Floating Valve-seat type poppet Valve).

5 Valve for the KAIHO-Engine.

The Valves for the KAIHO-Engine must,

- Need little force to operate under high pressure-difference for a large diameter valve.
- Open instantly and fully and opening period is long in the cycle.
- Can work at high rotational speed.
- Is simple structure and of high practicability.

The Floating Valve-Seat type Poppet Valve was invented and developed for this purpose. (VALVE SYSTEM AND EXTERNAL-COMBUSTION, CLOSED-CYCLE THERMAL ENGINE (Floating Valve-Seat type Poppet Valve) Patent: JPN 6173080).

The principle of it is shown in Fig 5-1.

At ordinary poppet valve, the valve opens to high-pressure side and the valve-head is pressed by the pressure difference against the valve-seat to airtight the valve.

Quite large force is necessary to open the large diameter valve against large pressure-difference.

On the contrary, at the Floating Valve-Seat type Poppet Valve, the valve opens to low pressure side. No force is needed to open. When it is closed, the valve-head is fixed by supporting system and floating valve-seat is pressed by the pressure difference to the valve-head to airtight while the floating valve-seat is supported by the elastic seal and can move short distance (floating distance, give the tolerance to the system, 0.5mm at the case of Fig5-2)

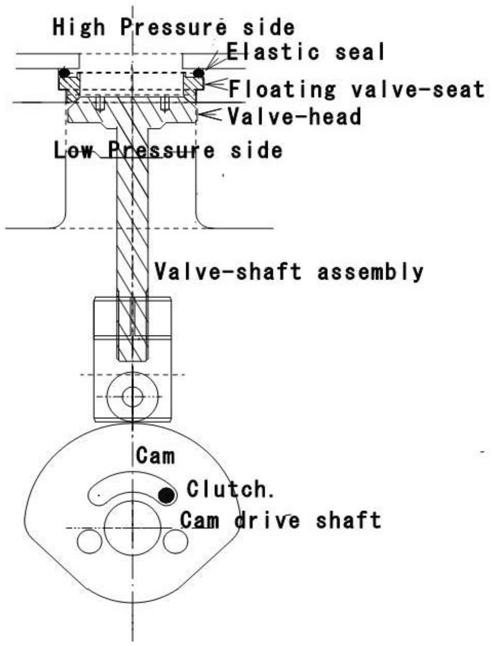


Fig 5-1 Principle of the Floating Valve-Seat type Poppet Valve

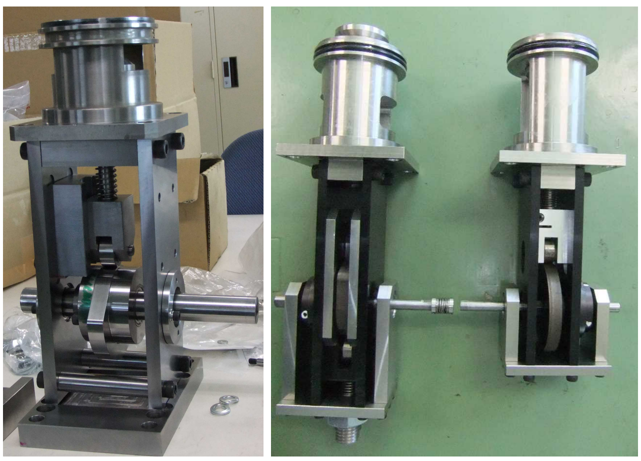


Fig 5-2 Floating Valve-Seat type Poppet Valves

The valve-head is supported by the cam via valve shaft and the roller.

The drive shaft of the cam rotates at the constant speed, but when the cam comes off, the cam become free by the clutch.

The valve opens instantly pushed by the pressure difference (The valve driven by an electric motor does not need clutch and the double shaft system for the clutch.)

A pilot model and one set of test model for practical use (intake and exhaust valve), both 40mmφ, 12mm stroke and 0.5mm floating distance, were built and tested with satisfactory results.

A pilot model and test models for practical use (intake and exhaust valve)

The pilot model worked to 10rps and could handled by hand under water pressure of 2Mpa.

Test models for practical use (intake and exhaust valves) were installed to a two-cylinder piston engine and driven by air pressure. They could follow the operating sequence required for the engine precisely and proved the practicality of the Floating Valve-Seat type Poppet Valve .

The floating valve-seat type poppet valve has more merits.

Fig 5-3 Two-cylinder piston engine

- Can be driven and controlled by electric (step)motor remotely
- Can be built, tested and installed indepently to the engine.
- Loose tolerance for the structure.

The floating valve-seat type poppet valve for the engine must be heat-proof. The metal floating valve-seat was proposed. Elementary experiment with flat metallic plate ring got good result.

An idea of practical floating valve-seat type poppet valve for the KAIHO-Engine, with metal heat-resistant floating valve-seat, and driven by an electric (step) motor is proposed in Fig 5-4.

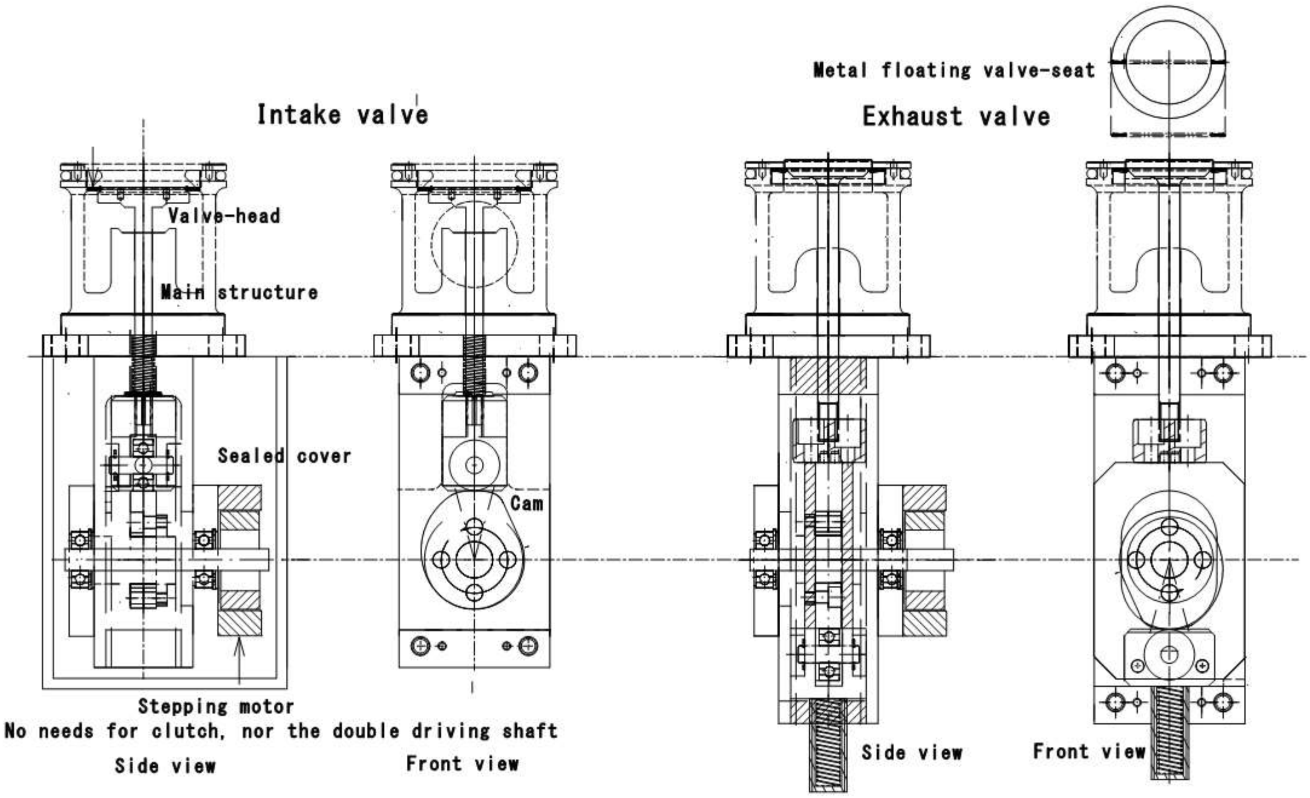


Fig 5-4 Proposed practical floating valve-seat type poppet valve (metal floating valve-seat (heat proof), motor driven)

6 The Thermal Cycle of the KAIHO-Engine : the Brayton Cycle. (Fig 6-1, 2, 3, (Fig 1). Table 6-1).

At the KAIHO-Engine, the volume of the part which does not change (can be increased easily by using a buffer tank) is much bigger compared with the part which changes and the pressure in the heater, the cooler and the regenerator are practically constant (Fig 4-4).

In case of 4units of the proposed case at Fig-1 (piston cylinder of 100mmφ, expansion cylinder of 130mmφ, stroke common 100mm) combined were using the heater, cooler, regenerator system of the 2012 Model KAIHO-Engine (Fig 4-4), resulting change of the volume is about 0.1% for the high-pressure portion (the heater, high pressure portion of the regenerator and the piping, plus the buffer tank, if needed), about 0.3% for the low-pressure portion (the cooler, low pressure portion of the regenerator and the piping, plus the buffer tank, if needed) is much larger than the part which changes (the displacement of the piston cylinders) and the resulting pressure change is 0.1% in the heater and about 0.3% in the cooler (Table 6-1).

Also, the flow of the working gas of the KAIHO-Engine is one directional and one set of a heater and the cooler can be used by the plural number of the engines. A KAIHO-Engine generates power 3/4 of the cycle. The working gas flows through the heater or the cooler 1/2 of the cycle.

With 4 unites of the KAIHO-Engine combined, the output is continuous and smooth. The heater, the cooler and the regenerator works through all the cycle.

The movement of the working gas and change of the volume for the 4unit multiple engine are shown in Fig 6-1.

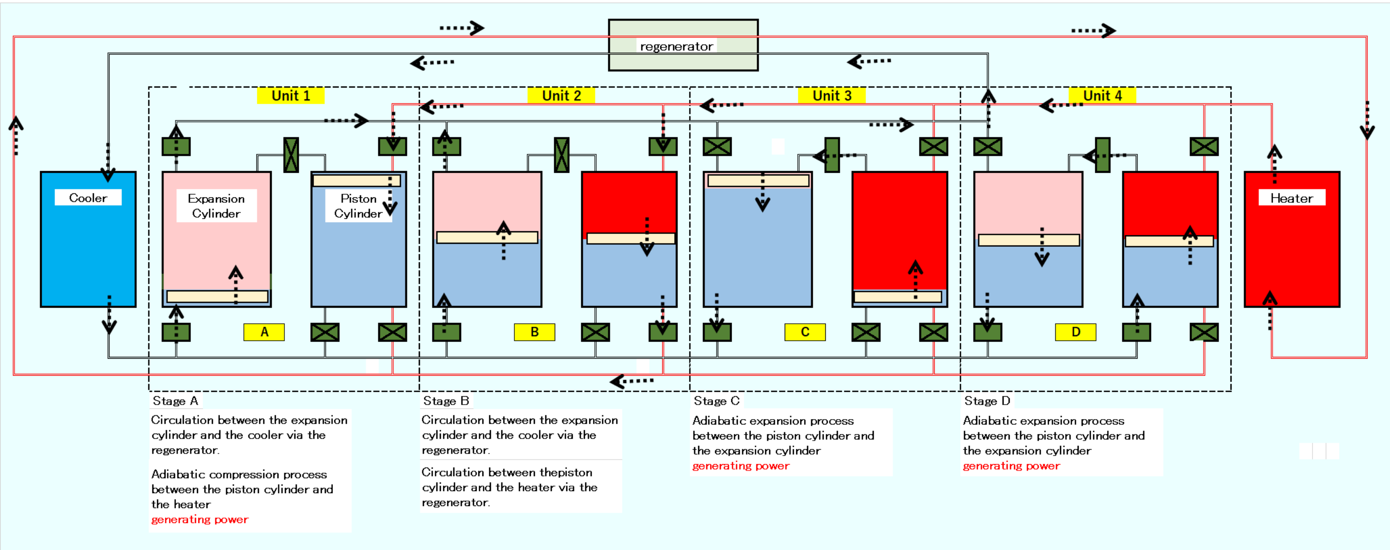


Fig 6-1 Configuration of 4units combined Multi KAIHO-Engine

Table 6-1 The Pressure Fluctuation at the KAIHO-Engine, 4units combined

Volume		Volume （ℓ）	Pressure fluctuation （%）
Fixed Part 2012 Model	High pressure Portion*	445	0.1
	Low pressure Portion**	265	0.3
Fluctuate Part NE3CB-S Engine***	High pressure Portion	0.4	
	Low pressure Portion	0.8	

* the heater, high pressure portion of the regenerator and the piping
** the cooler, low pressure portion of the regenerator and the piping
*** Piston Cylinder (10cmφ×10cmSt)

For the practical purpose, at the multiple KAIHO-Engine, P_H, and P_L are constant and is Brayton Cycle.

7 The performances of the KAIHO-Engine (Fig 7-1, 2, 3, 4, 5).

With the assumption of Brayton Cycle, theoretical Temperature-Pressure cycle for the proposed case is shown in Fig 7-1 and P-V chart is in Fig 7-2. Calculated performances are shown at Table7-1 and Fig 1-1.

With large heater, cooler, regenerator and piping, the problem of flow resistance is not a serious problem at the multiple KAIHO-Engine system. Various kind of working gas can be used. The effect of the working gas is shown at Table7-1 and Fig 1-1.

Output per displacement of the H_2 gas is small. The characteristics of the He gas and Ar gas are almost identical.

In case the efficiency of the regenerator is below 80%, Ar gas might be the best. It should be investigated preciously at the stage of the development which working gas to use.

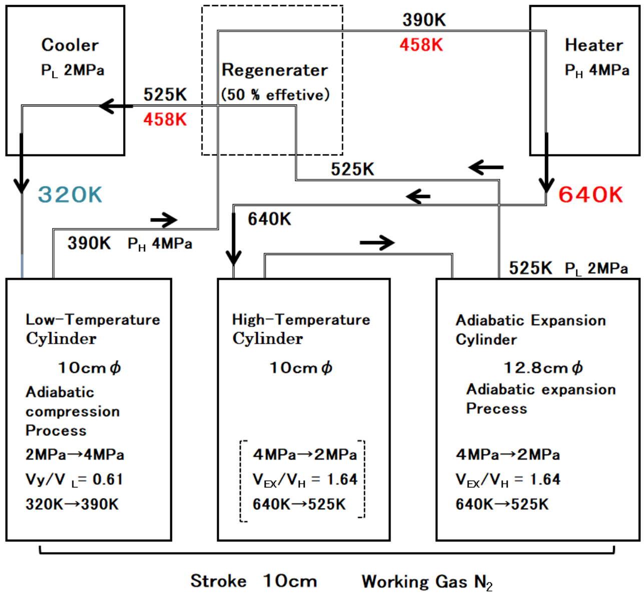


Fig 7-1 Temperature-Pressure cycle of the proposed case

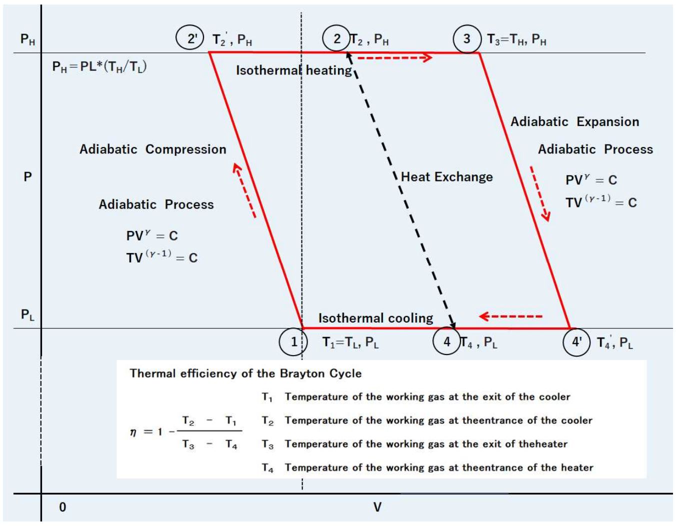


Fig 7-2 P-V Chart for the KAIHO-Engine

Table 7-1 The effect of the Working Gas, the efficiency of the Regenerator and the diameter of the expansion cylinder

	0% (Efficiency of the Regenerator)					50%					70%					*φ_E cm	
W.Gas	H_2	He	N_2	Ar	CO_2	H_2	He	N_2	Ar	CO_2	H_2	He	N_2	Ar	CO_2	N_2	Ar
300°C	16.1	20.7	15.4	20.6	12.6	21.7	24.3	21.2	24.3	18.7	25.3	26.2	24.9	26.2	23.2	12.3	11.9
400°C	20.1	25.6	19.2	25.5	15.8	26.8	29.9	26.2	29.9	23.2	31.0	32.1	30.6	32.1	28.5	13.0	12.5
500°C	23.3	29.6	22.3	29.5	18.5	31.0	34.4	30.2	34.4	26.9	35.6	36.9	35.2	36.9	32.8	13.7	13.0
600°C	26.1	32.9	25.0	32.8	20.8	34.4	38.1	33.6	38.1	30.0	39.4	40.7	38.9	40.7	36.4	14.3	13.5
700°C	28.5	35.7	27.3	35.6	22.7	37.3	41.3	36.4	41.2	32.6	42.6	44.0	42.1	44.0	39.4	14.9	14.0
800°C	30.5	38.2	29.3	38.1	24.5	39.8	43.9	38.9	43.9	34.8	45.3	46.8	44.8	46.8	42.0	15.4	14.4
900°C	32.4	40.3	31.1	40.2	26.0	42.0	46.3	41.1	46.2	36.8	47.6	49.2	47.1	49.2	44.2	15.9	14.8
1000°C	34.0	42.2	32.7	42.2	27.4	43.9	48.3	43.0	48.3	38.6	49.7	51.3	49.1	51.3	46.2	16.4	15.2

	80%					100%					Kw				
W.Gas	H_2	He	N_2	Ar	CO_2	H_2	He	N_2	Ar	CO_2	H_2	He	N_2	Ar	CO_2
300°C	27.5	27.2	27.4	27.3	26.3	33.4	29.6	34.0	29.6	36.1	1.3	4.3	5.1	4.3	5.7
400°C	33.7	33.4	33.5	33.4	32.2	40.5	36.1	41.2	36.2	43.5	2.2	7.7	9.1	7.7	10.1
500°C	38.5	38.2	38.3	38.2	36.9	46.0	41.2	46.7	41.3	49.2	3.4	11.6	13.8	11.6	15.4
600°C	42.5	42.2	42.3	42.2	40.8	50.4	45.4	51.1	45.4	53.7	4.7	16.1	19.1	16.1	21.3
700°C	45.8	42.2	42.3	42.2	40.8	54.0	48.8	54.8	48.9	57.4	6.1	20.9	25.0	20.9	34.8
800°C	48.6	48.3	48.4	48.3	46.7	57.1	51.8	57.8	51.8	60.5	7.6	26.2	31.2	26.1	34.8
900°C	51.1	50.8	50.8	50.8	49.1	59.7	54.3	60.4	54.3	63.1	9.2	31.7	37.8	31.6	42.1
1000°C	53.2	52.9	52.9	52.9	51.2	61.9	56.5	62.7	56.5	65.4	10.9	37.5	44.7	37.4	49.9

* φ_E Diameter of the expansion cylinder

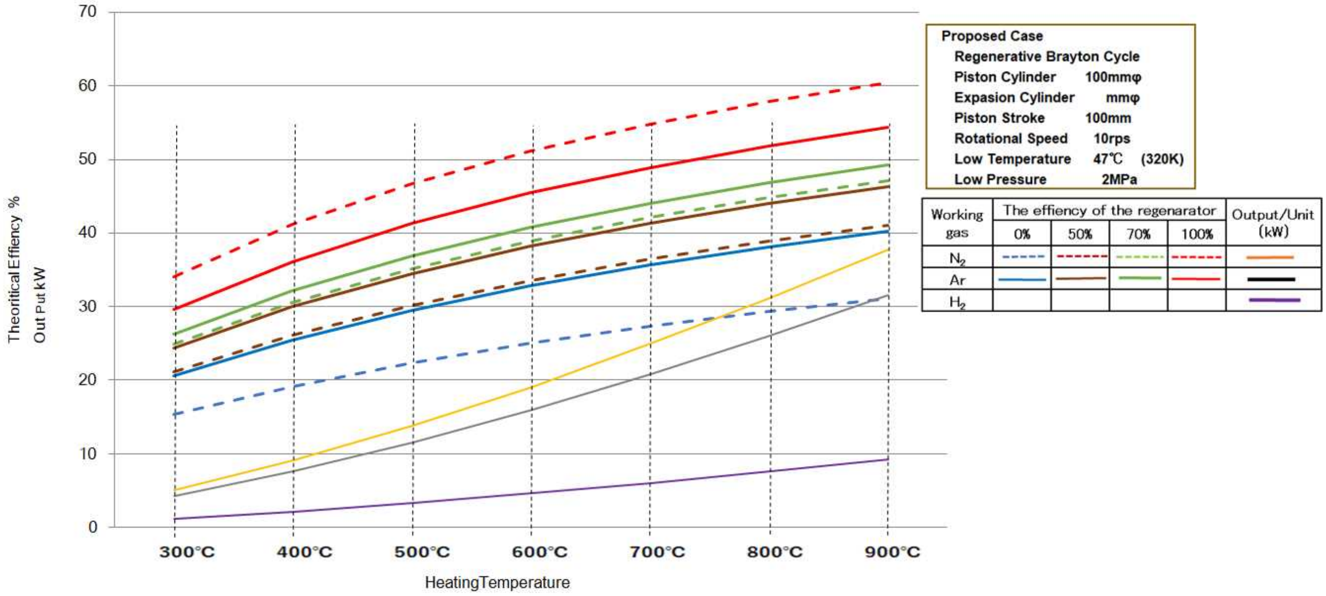


Fig 1　Theoretical Performances of the KAIHO-Engine and the effect of the Working Gas for the proposed case

8　Proposal for the practical KAIHO-Engine.

An idea for the practical KAIHO-Engine is shown in Fig 8-1.

Double acting type with motor driven valves.

Double acting type has following merits.

- The number of the pistons is reduced to half. The frictional resistance become half. The structure of the piston is simple and receive no side force.
- Simple structure and small blocks. Main parts of the Engine are only holed blocks. No problem by usual engine technology.
- The piston-shaft seal is less difficult than piston seal for the ordinary Stirling engine.
- The piston-shaft is thin and receive no side force.
- Can be oil- lubricated, and can be cooled.
- Airtightness is kept by rotating shaft (crank shaft) seal only.

The merits of the motor driven valve are,

- No need for the mechanical valve driving shaft system.
- No trouble to separate the flow path of hot, cool, high pressure, low pressure working gas.
- Can be controlled remotely.　Can be opened or shut at any point, useful features especially at starting times or emergency.
- Can be manufactured, encased, sealed, tested, installed independently. No need for the accuracy to be installed.

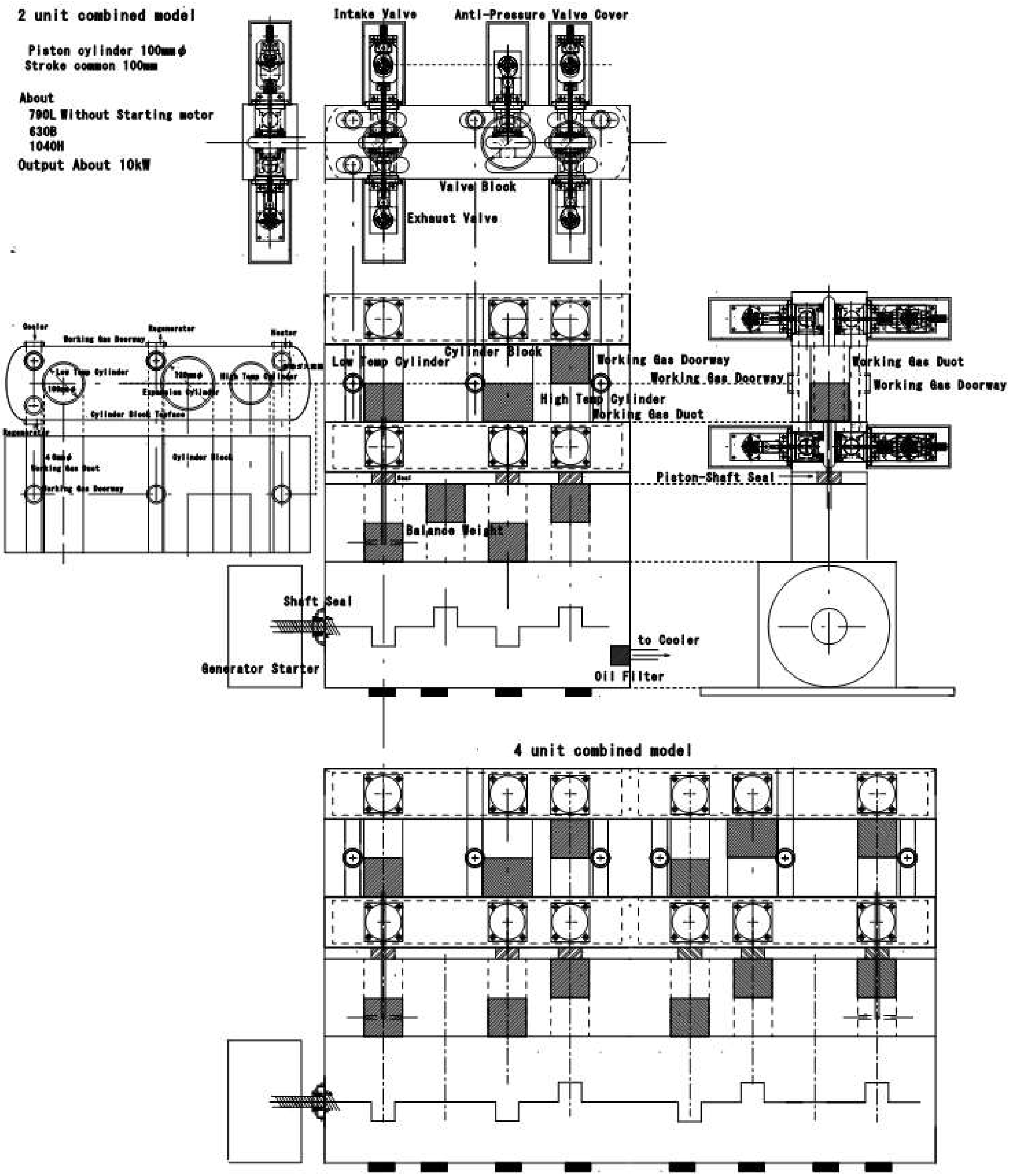


Fig 8-1 Proposed Multiple KAIHO-Engine : Double acting type with motor driven valve.

The general configuration of multiple KAIHO-Engine system is shown in Fig 8-2. In case of emergency, each engine (double acting) can be stopped, by shutting valves in the engine. Phase difference between the engines can be easily adjusted (this case from 90°to 180°) remotely.

By opening the by pass valve, the pressure in the heater and the cooler become equal and the power output become zero, but by keep rotating the engine by starting motor or other method, the circulation of the working gas can be kept and protect the heater to seizure.

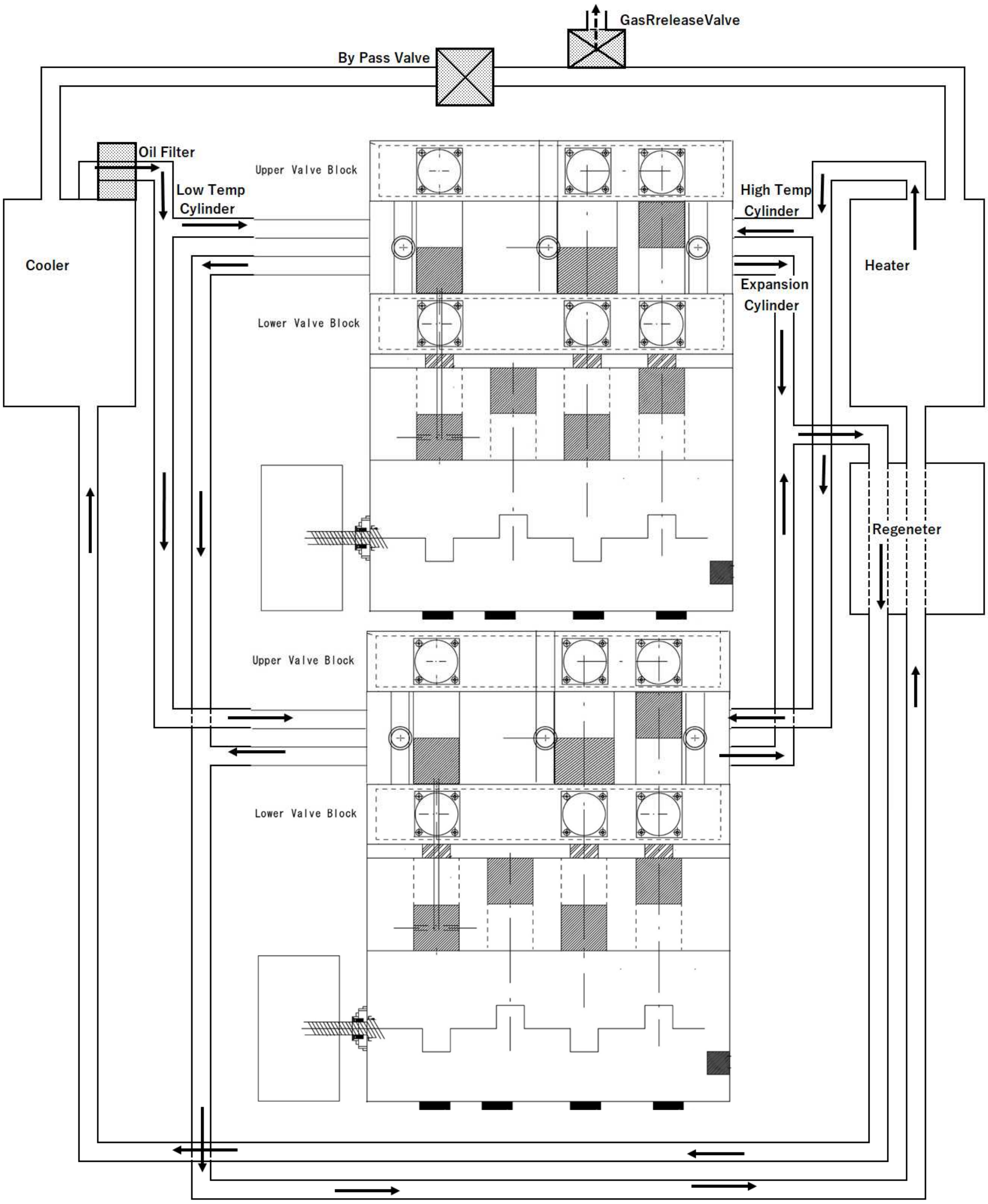


Fig 8-2 Proposed Multiple KAIHO-Engine System: Double acting type with motor driven valve.

The working gas can be evacuated by opening the gas release valve. It is easy to refill the working gas since it is Ar or N_2 gas. Maintenance is easy.

9 Remaining problems and the future plan

The KAIHO-Engine is an entirely new system. Many troubles must be expected. Among them,

- The valves.

The floating valve-seat type poppet valve was proposed for the KAIHO-Engine. It must be heat-proof.

The metal floating valve-seat was proposed. It must withstand the repeated load at high temperature.

The elongation ratio is less than 0.06% at the proposed case.

Ordinary heat resistant spring can withstand temperatures up to 650℃. For better effiency, new materials or some cooling devices are necessary.

- The heater.

The plate-type heater used at the 2012 Model KAIHO-ENGINE will have no trouble with clean combustion gas, hoever will be easily clogged by the combustion gas with burnt residue like biomass fuel.

- Effective way to filtering out the ash. or
- Effective way to prevent the ash to attach the heater. or
- Effective way to cleanse the heater. or
- Another type of heater resistant to the ash.

is needed.

- Material
- The weight of engine must be reduced. A light, heat resistant, strong material is needed.
  Ceramic is a promising candidate, since the main partsof the engine are only holed blocks.
- The way to make break through

The KAIHO-Engine will have high commercial value with biomass fuels. However, engine technology must be established before the heater problem.

Special purpose engine might be the way to make the break through.

- Hydrogen Engines
  Hydrogen fuel produce no burnt residue while KAIHO-Engine has little combustion problem since it is an outer combustion engine.
- The power plants at the sea floor
  Under high pressure circumstances, filling pressure can be very high. A small engine can generats high power combustion combustion.
- The underwater power plant
  The KAIHO-Engine can replace the ordinaly Stirling engine for the submarine with its high practicality and Ar gas or N2 gas as the working gas. Also, another advange is that it can work as the air-breathing engine on the surface.
  KAIHO-Engine can replace both of the ordinaly Stirling engine for underwater and the Diesel engine for the surface.
  These must be a quite advantage for a small or midget submarine.

10 Patents

Table 8-1 Patents

EXTERNAL-COMBUSTION, CLOSED-CYCLE THERMAL ENGINE	Japan 4520527
	US 8938942B2
VALVESYSTEM and EXTERNAL-COMBUSTION, CLOSED-CYCLE THERMAL ENGINE (Floating valve-seat type poppet valve)	Japan 6173080