International Green Energy Business Conference
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# Development of Hydrogen-fueled linear power/ generation system

International Green Energy Business Conference 2011

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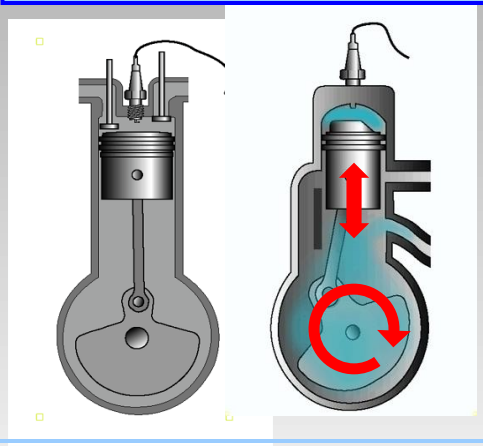
EngineTech.CO.,LTD

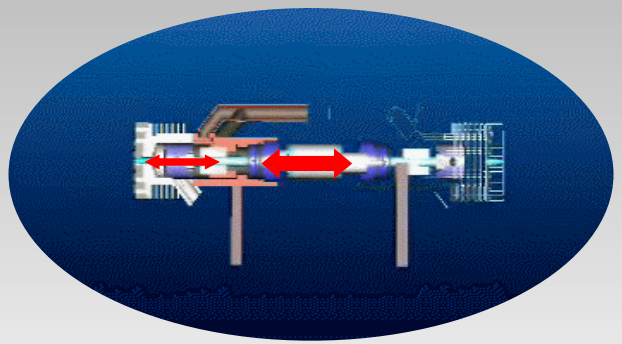
# 리니어 동력/발전 시스템이란?

리니어엔진의 직선운동을 리니어발전기를 통해 전기에너지로 변환하는 장치

**Conventional Engine**



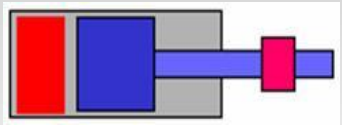
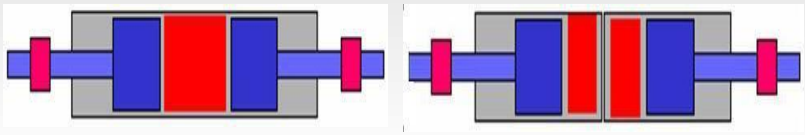
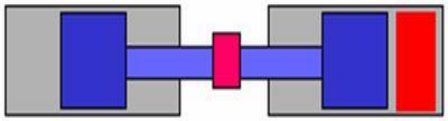
**Linear Engine + Generator**



- 동력손실 최소화 에너지변환 → 40% 이상의 고효율, 고비출력 기관 실현
- 기존 기술/제작 인프라 사용 → 개발/제작비용 절감
- 소형, 경량화 가능 →Crankless 기관

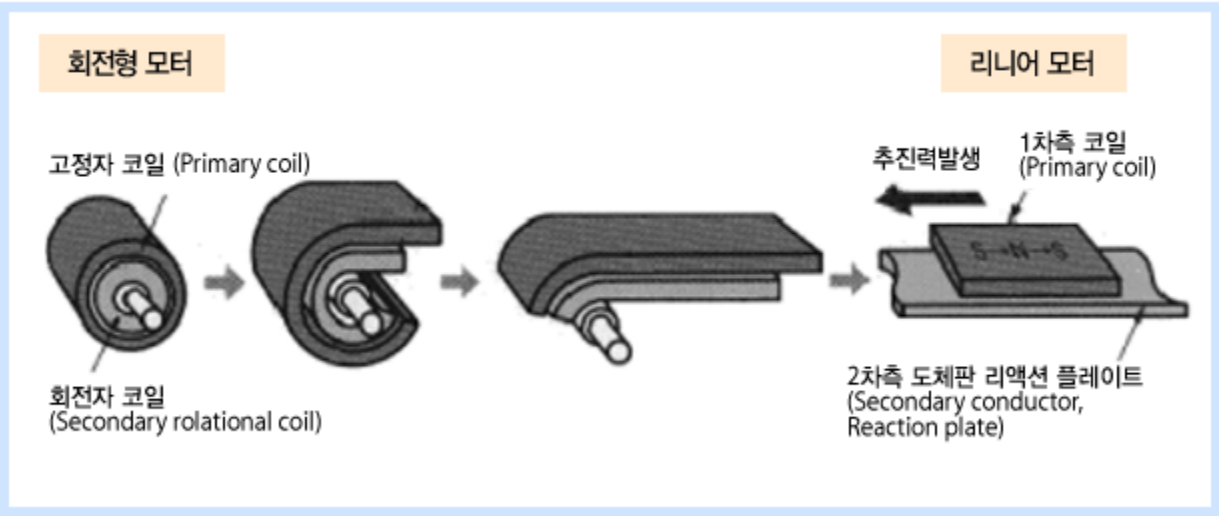
## 엔진 효율의 한계를 극복 – *리니어 엔진*

- 크랭크 기구가 없는 엔진
- 엔진이 하나의 축으로 직선 형태로 연결된 형태의 엔진
  (선형, Linear 엔진으로 명칭 함)
- 유압펌프, 발전기 등의 에너지 변환장치가 필요함
- Lean Burn, 고압축비 실현이 가능한 엔진으로 50% 이상의 열효율 달성 가능 엔진

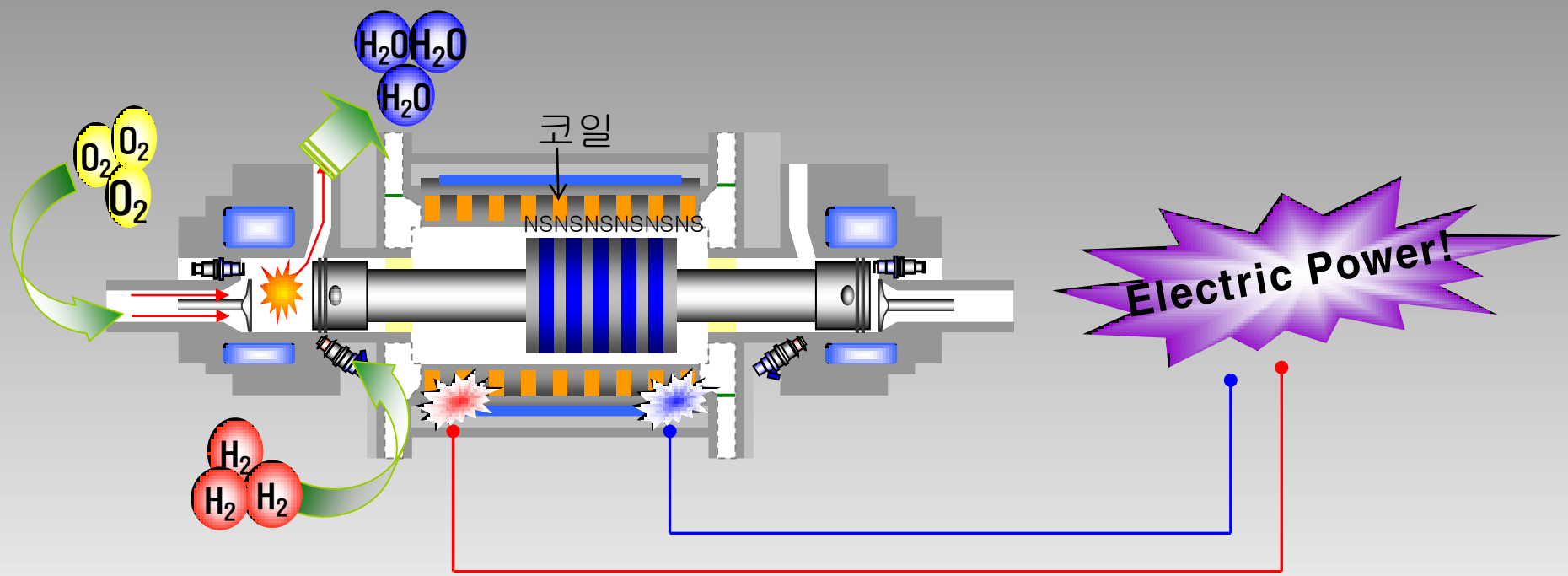
| 구 분 | 형 태 |
|---|---|
| Single Piston Type |  |
| Opposed Piston Type |  |
| Dual Piston Type |  |

# 엔진의 동력을 손실없이 전기E로 변환 – *리니어 발전기*

- 리니어엔진의 직선 왕복운동을 전기에너지로 변환
- 일반 회전형 모터를 축 방향으로 잘라서 펼쳐놓은 형태



# 시스템의 원리




## 연소

$$2H_2 + O_2 \rightarrow 2H_2O$$

## 에너지변환

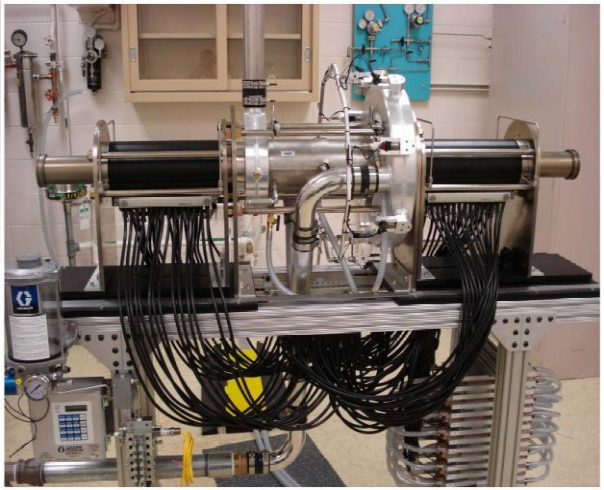
운동E ➡ 전기E

## 이용

# 국내/외 연구동향

## Sandia National Lab.

- Free Piston Hydrogen Engine
- HCCI (near 0 NOx , $\eta_i$ = 56 %)
- Linear Alternator (96 %)
- 2010 Goal
  (Total Efficiency : 50 %, 20 $/kW)



## Pempek Systems Pty. Ltd.

- Free Piston Engine for Hybrid Vehicle (100 kW, DISI, 8 Cylinders, 2.82L)
- Integrated Design (Many space saving features, enable it to fit easily into the engine bay of existing passenger vehicles)
- Prototype is complete an testing is in progress

## West Virginia Univ.

- Free Piston Engine (2 Cycle, SI) with Linear Generator
- 10 kW for Series Hybrid Vehicle Demonstration

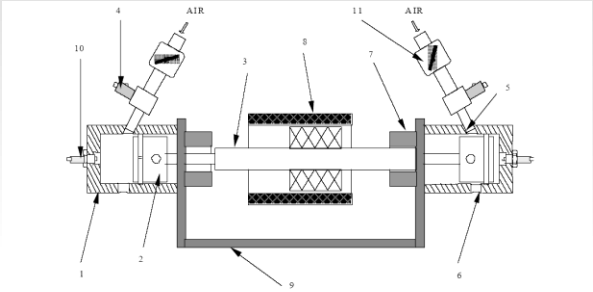
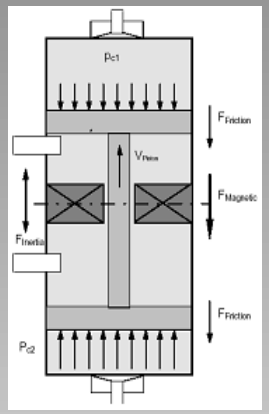
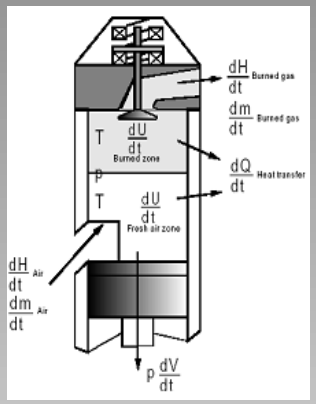



Figure 1. Geometric Layout of the Prototype Two-Stroke Cycle Linear Engine-Alternator Combination modeled in this work. (1. Cylinder, 2. Piston, 3. Connecting Rod, 4. Pulsed Solenoid Fuel Injector, 5. Intake Port, 6. Exhaust Port, 7. Motoring Coil, 8. Linear Alternator, 9. Frame, 10. Spark Plug, 11. Throttle)

## FEV Engine Technology

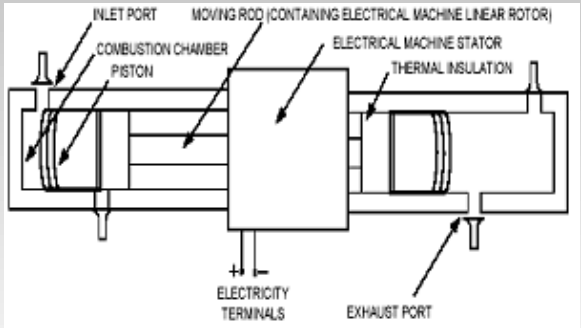
- Evaluation of Different Hybrid Vehicle Configuration
- Development of Numerical Simulation Model
- Effects of piston mass, electromagnetic strength, exhaust valve timing, combustion timing etc.





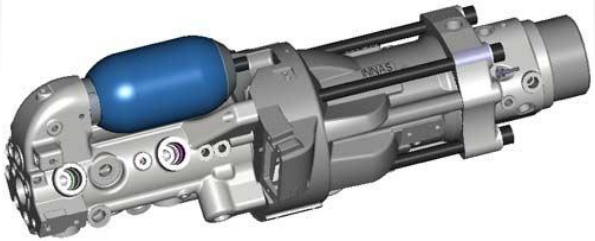
## Royal Institute of Technology

- Free Piston Engine-Generator (50 kW for Series Hybrid)
- Development of Simulation model (using Matlab)
- Development of Control Logic



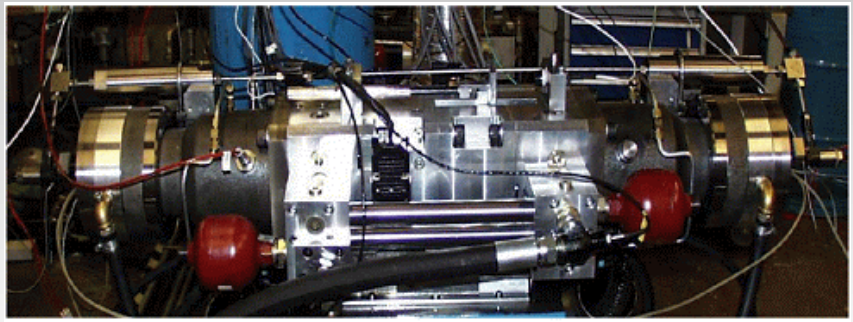

## INNAS B.V.

- Free Piston Pump (Single Piston type, CRDI, 17 kW, ηi = 50 % Dry Weight : 90 kg)
- Free Piston Generator (Started in 2002, Supported by the EU)



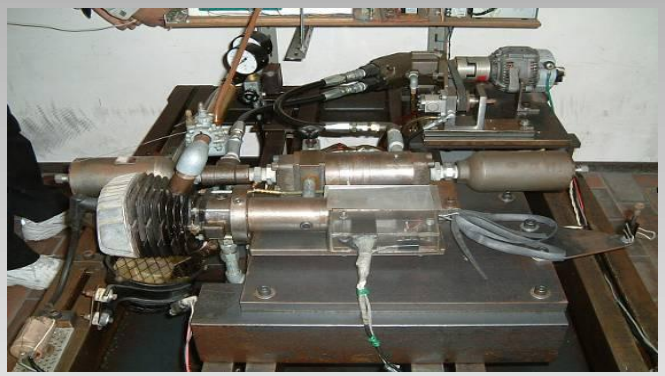
## Helsinki University of Technology

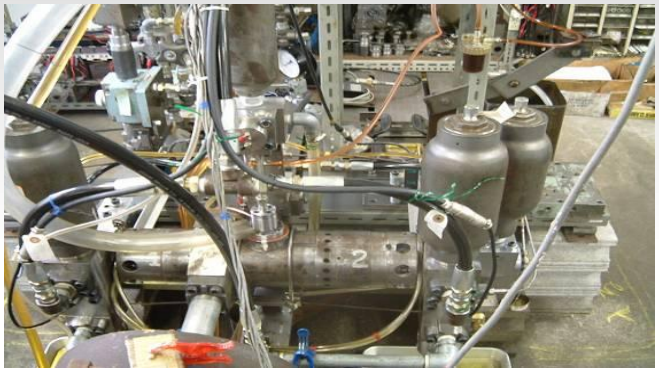
- Free Piston Hydraulic Engine
- Stroke : 112 ~ 114 mm
- Cycle Frequency : 1700 /min (rpm)
- CRDI (1350 bar)
- Weight : 120 kg
- Power : 13 ~ 18 kW



## TUT (Hibi Lab.)

- Free Piston Engine-Pump (1980)
- Thermal Efficiency : 40%





## Toyota

- 고효율/저 Nox 수소 연소법 개발
- 경부하 : **Low penetration Nozzle**
  **ηi 52 % 달성**
- 경중부하 : 고압수소분사, 성층/확산연소
  **ηi 44.4 => 47.4%**
  **NOx 0.35g/KWh**
- 중고부하 : 성층/확산연소, **EGR**
  **ηi 40.2 => 43.8**
  **NOx 0.35g/KWh**

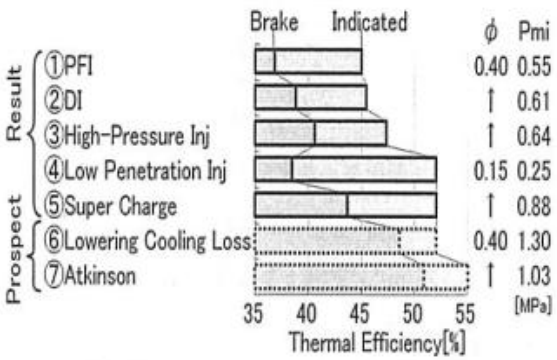


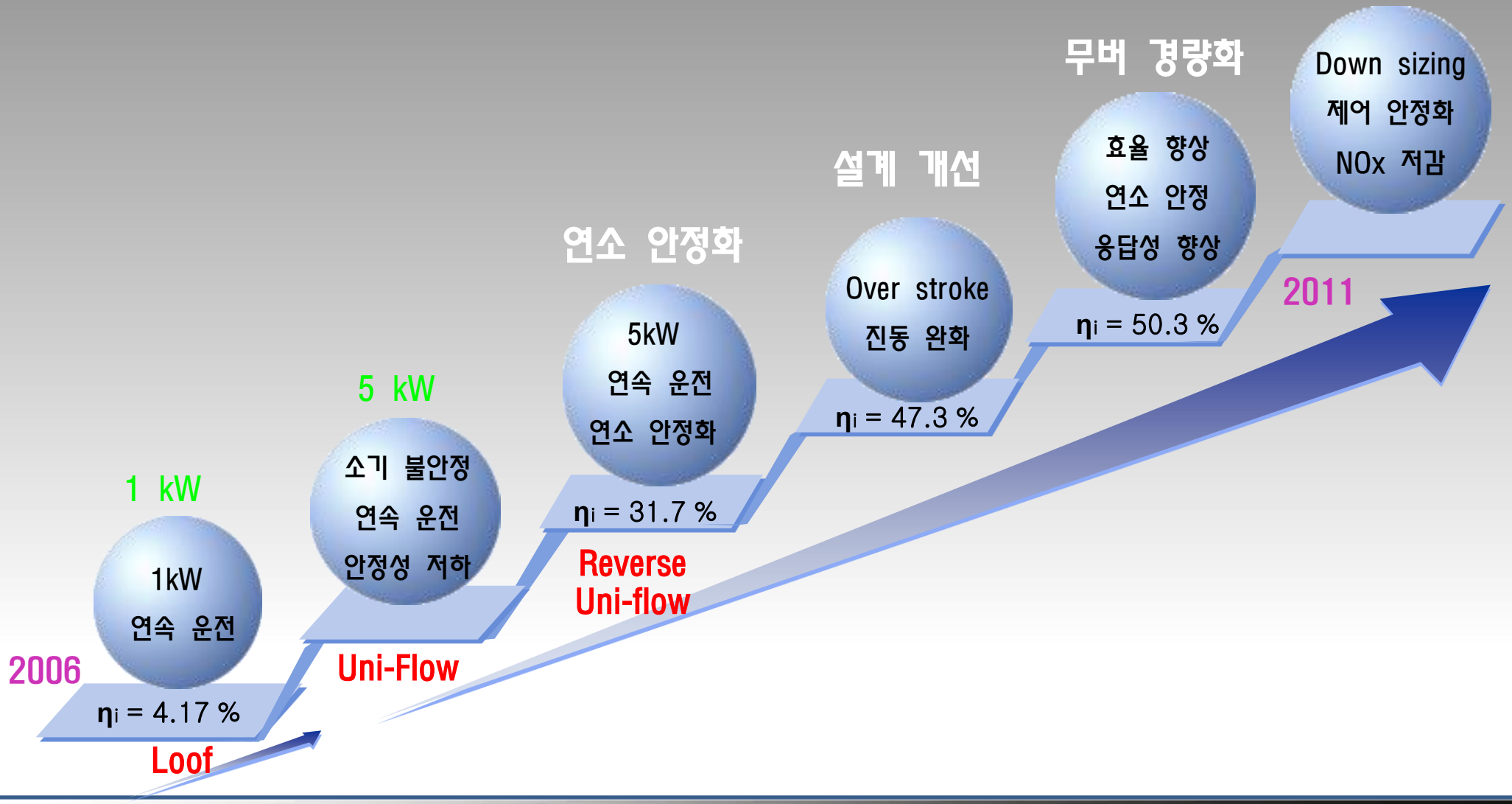

Fig.16 Improvement of Thermal Efficiency

## 경동 나비엔

- 스터링 열병합 발전 시스템 개발 부품 국산화가 목표

- 대한기계학회
  "1kW급 스털링엔진 열병합발전시스템의 시동특성에 관한 연구"
  "1kW 급 LNG 스털링 엔진을 위한 예혼합 버너의 연소 특성"

# 개발 History


2006
1 kW
1kW
연속 운전
ηi = 4.17 %
Loof
5 kW
소기 불안정
연속 운전
안정성 저하
Uni-Flow
연소 안정화
5kW
연속 운전
연소 안정화
ηi = 31.7 %
Reverse
Uni-flow
설계 개선
Over stroke
진동 완화
ηi = 47.3 %
무버 경량화
효율 향상
연소 안정
응답성 향상
ηi = 50.3 %
2011
Down sizing
제어 안정화
NOx 저감

# Power system

## ○ 연소 system

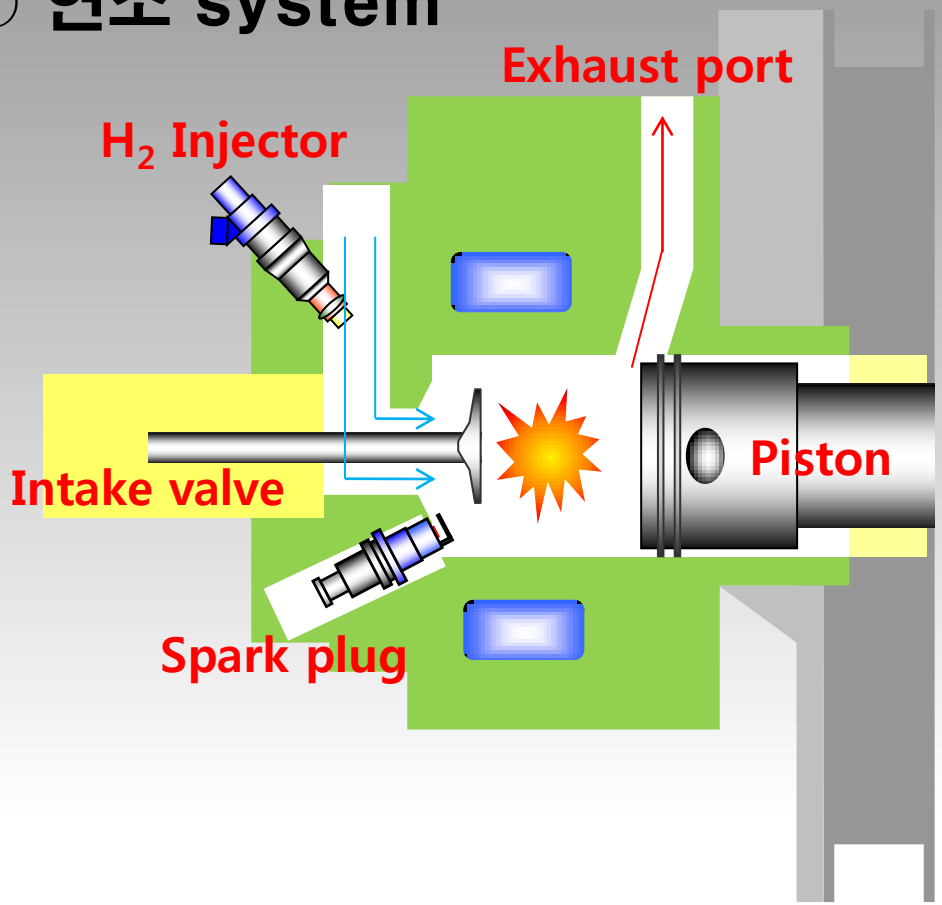
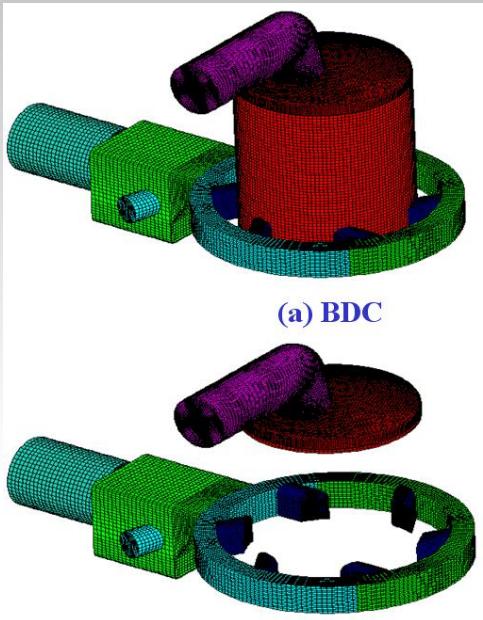



**Table. Specifications of the Linear Engine**

| | |
|---|---|
| **용량** | 5kW |
| Bore X Stroke | 77.7mm X 85(75)mm |
| Displacement | 403cc(355.6) |
| Compression ratio | 9.76(8.73):1 |
| Intake valve Open | TBD |
| Exhaust Port Open | BTDC 75mm |
| Moving mass | 8.6kg |
| **냉각방식** | **수냉식** |
| **윤활유 공급방식** | **실린더 벽면 강제 공급** |
| **소기 방식** | Reverse Uni-Flow type |

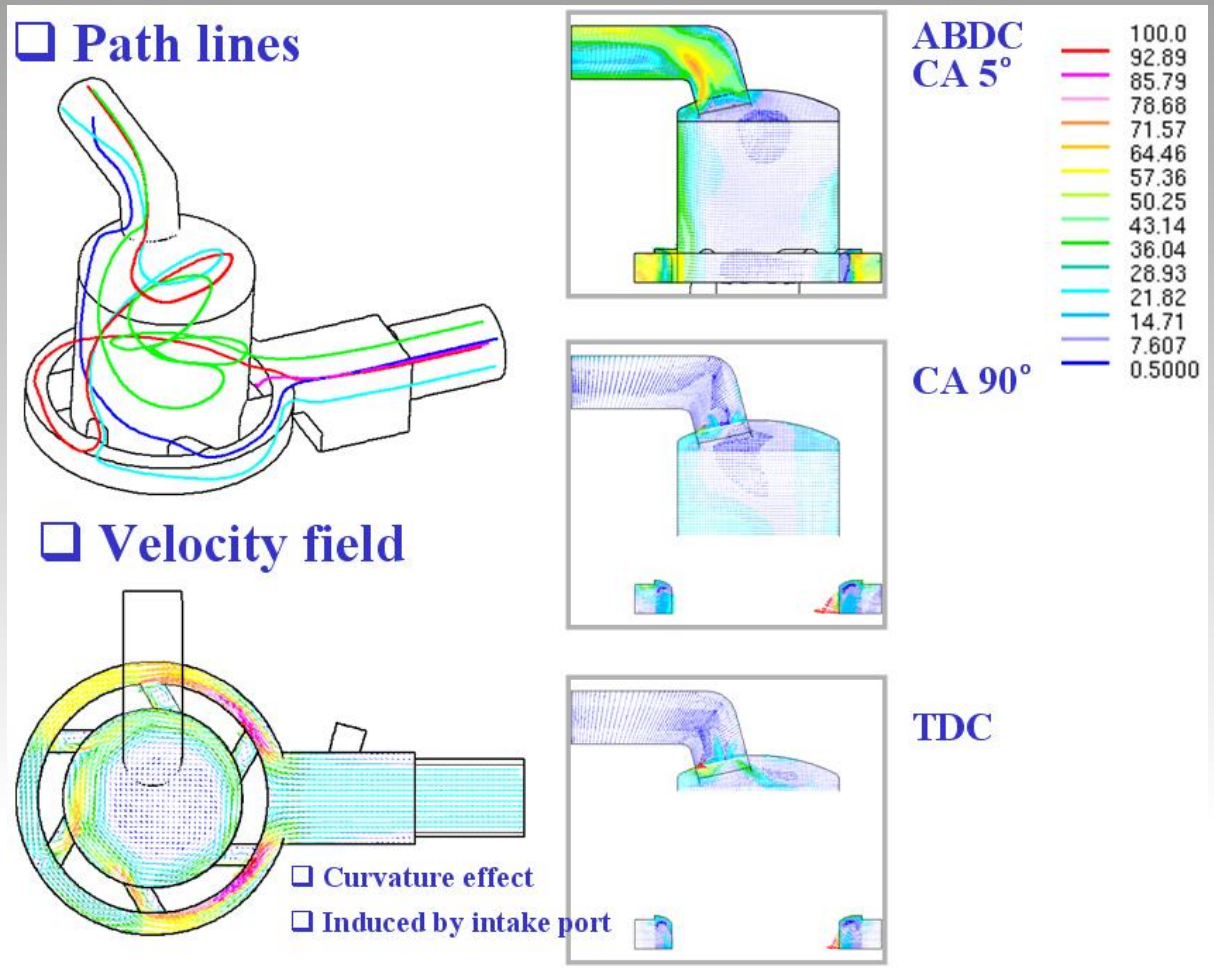
# ○ 유동 및 연소 해석

**Modeling of Geometry,**
**Valve Position & Timing,**
**Variable Stroke,**
**Intake Pressure, etc.**



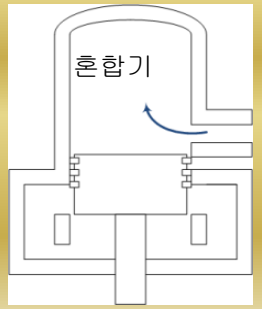
(a) BDC

(b) TDC

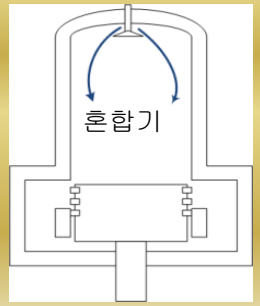


# ○ Reverse uni-flow 소기방식의 역화 적응성 및 적정 소기방식 제시

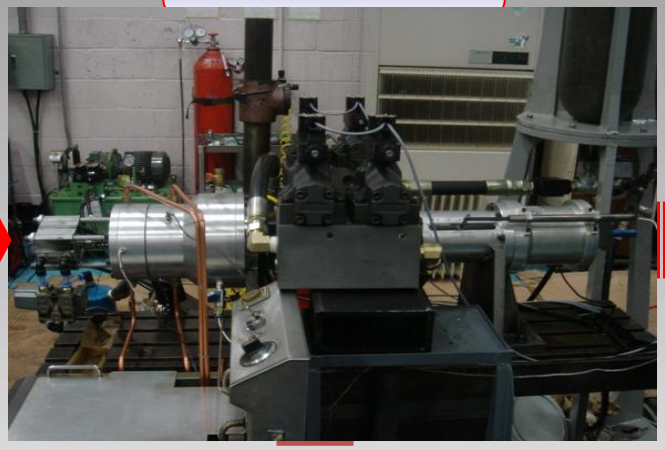
Loop




Reverse uni-flow




급속압축 팽창기



- 역화 발생 유무 및 역화 특성
- 역화 양상과 유동 측면 고려
- 각 소기 방식 연소 특성 비교

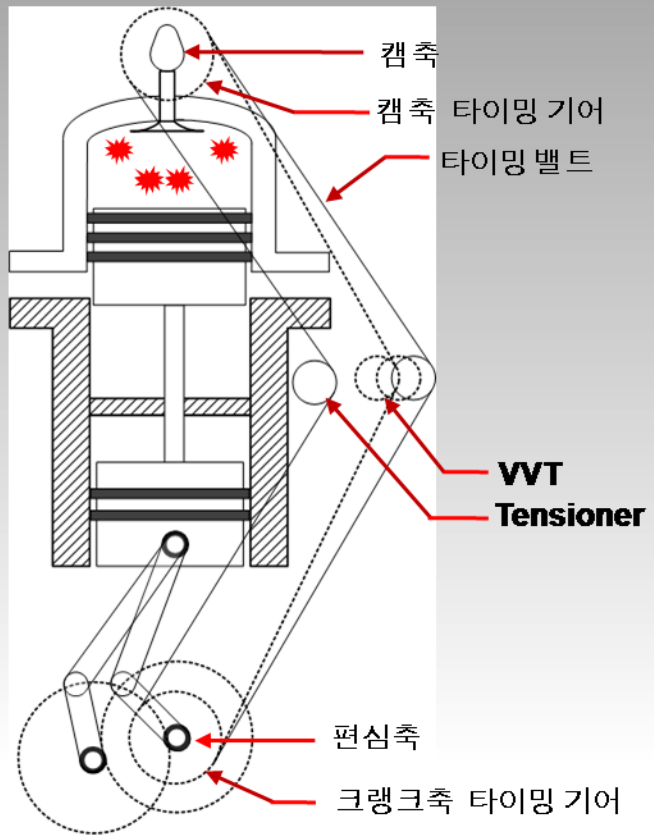
수소 연소 리니어
동력 시스템의 적정
소기 방식 제시

+

2 Stroke 프리피스톤
수소 연소 연구용
상사 기관 설계 및 기반 구성

# ○ $NO_x$ 저감 및 고효율 달성 전략 강구

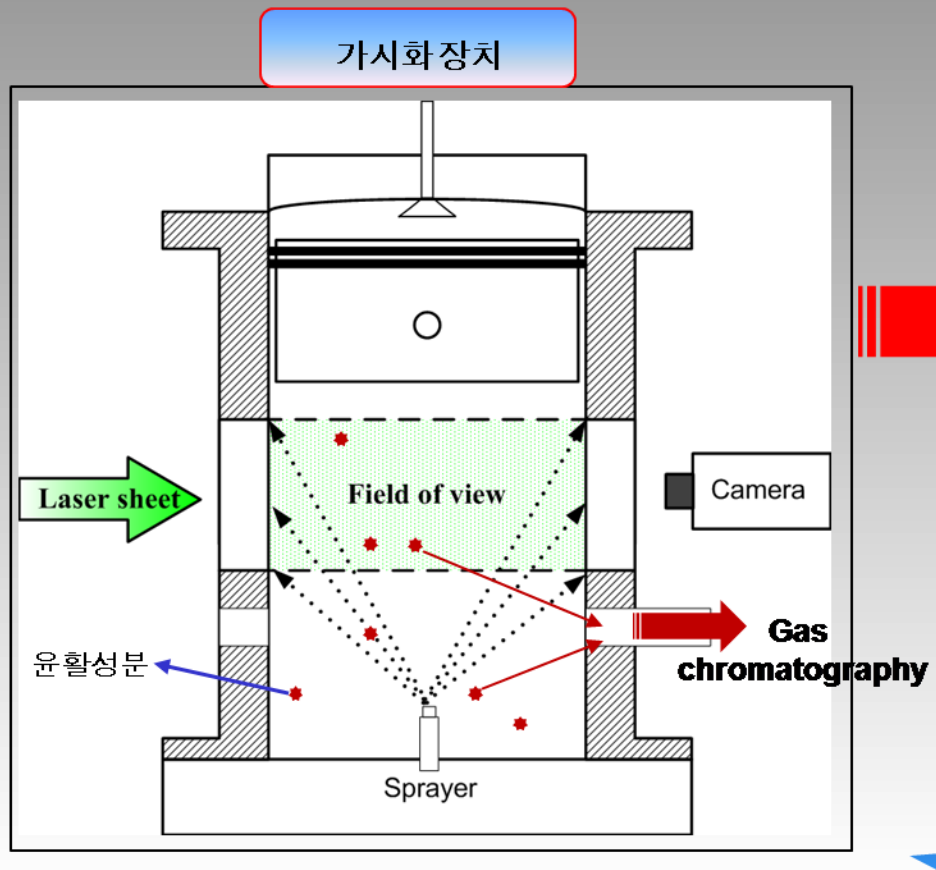
**2 Stroke 프리피스톤 수소연소 상사기관**




- 프리피스톤 기관 피스톤 변위 양상 실현
- NOx 감소 운전 영역 파악
- 비정상 팽창시의 NOx 특성
- 내부 EGR효과

고효율하의 NOx 감소 전략 제시

# ○ 프리피스톤 기관용 분리 윤활법 평가 및 최적화

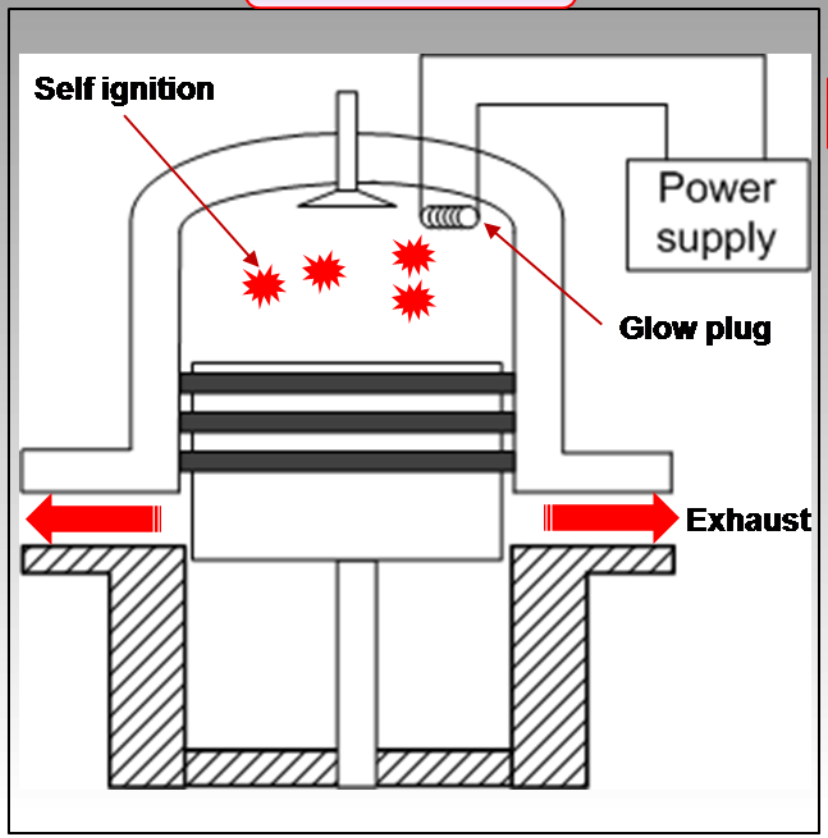



- 분리 윤활 장치 가시화
- 윤활 분포 해석
- 흡기 챔버내의 윤활 성분 평가
- 윤활유 회수 장치 개발

분리 윤활 방식 제시
및 최적화

# ○ 자기 착화에 의한 점화 개선 가능성 평가

자기 착화 시스템




- 자기 착화 시스템 구성
- 수소 연료 자기 착화 특성
- Glow plug에 의한 자기착화 개선

- 연소 효율 상승에 의한 효율 증가
- 점화 시스템의 간소화
- 제어 난해성 해결

점화 시스템 안정화 및 스파크 점화 대체 가능성

# Generation system

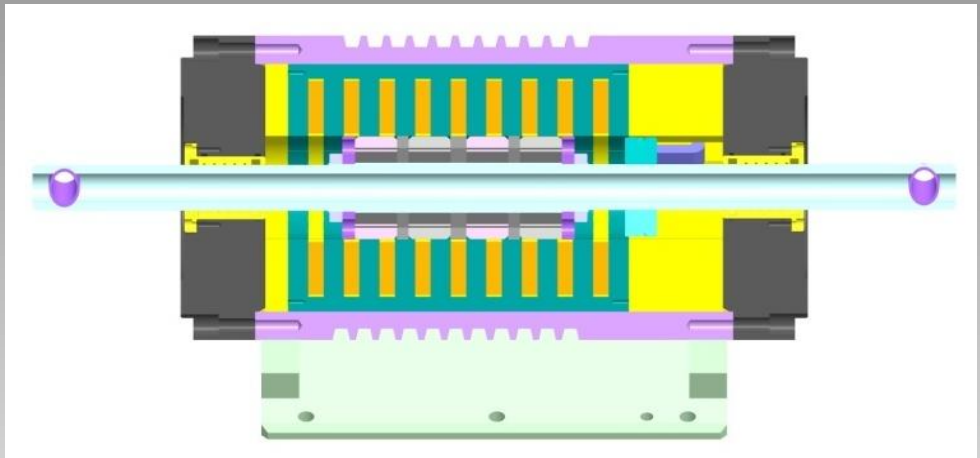
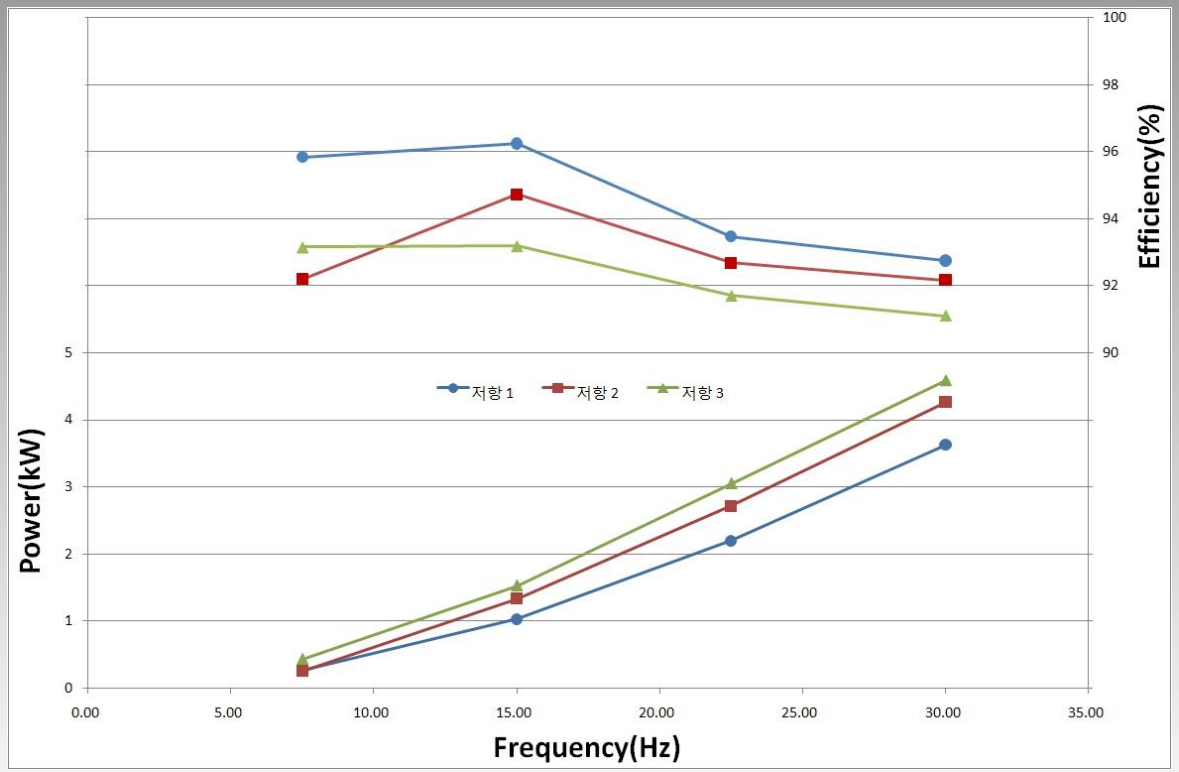
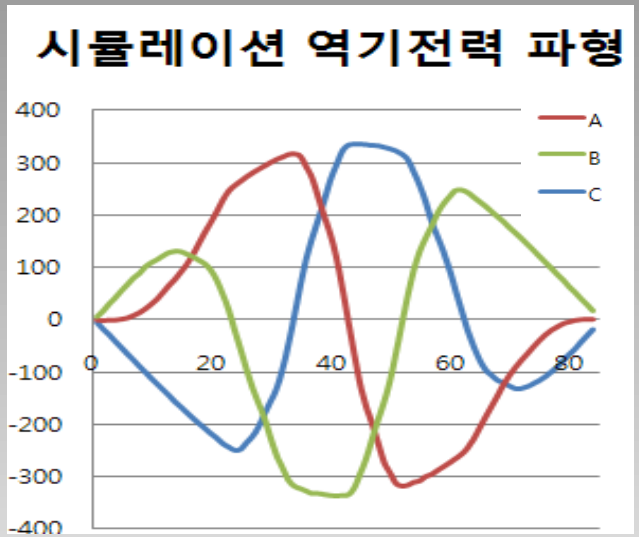


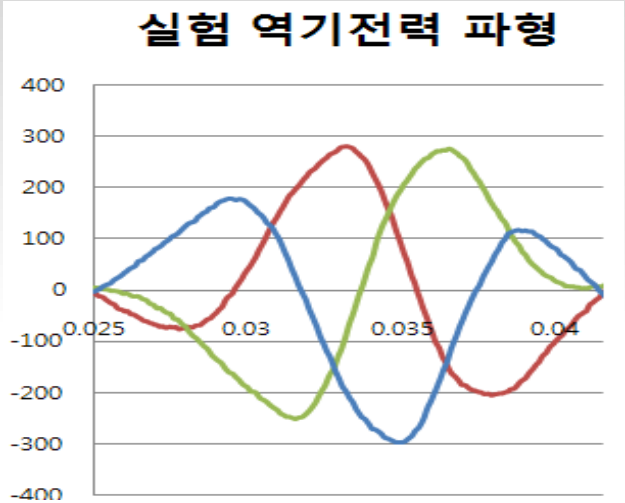
**Table. Specifications of the Linear Genenrator**

| Item | **Specification** |
|---|---|
| Power | **4.6[kW]** |
| Pole/Phase | **2 pole/3phase** |
| Stroke | **85[mm]** |
| Frequency | **30[Hz]** |
| Efficiency | **91.1%** |
| Max. $V_{peak}$ | **300 [$V_{peak}$]** |

# ○ 운전 속도 별 출력 및 효율



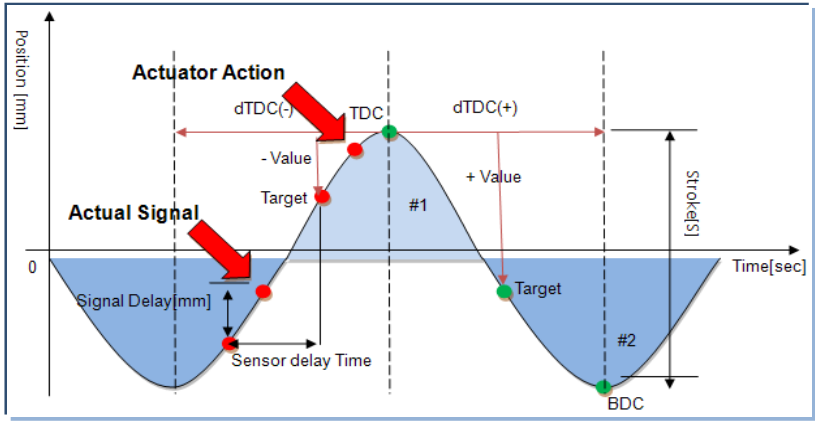



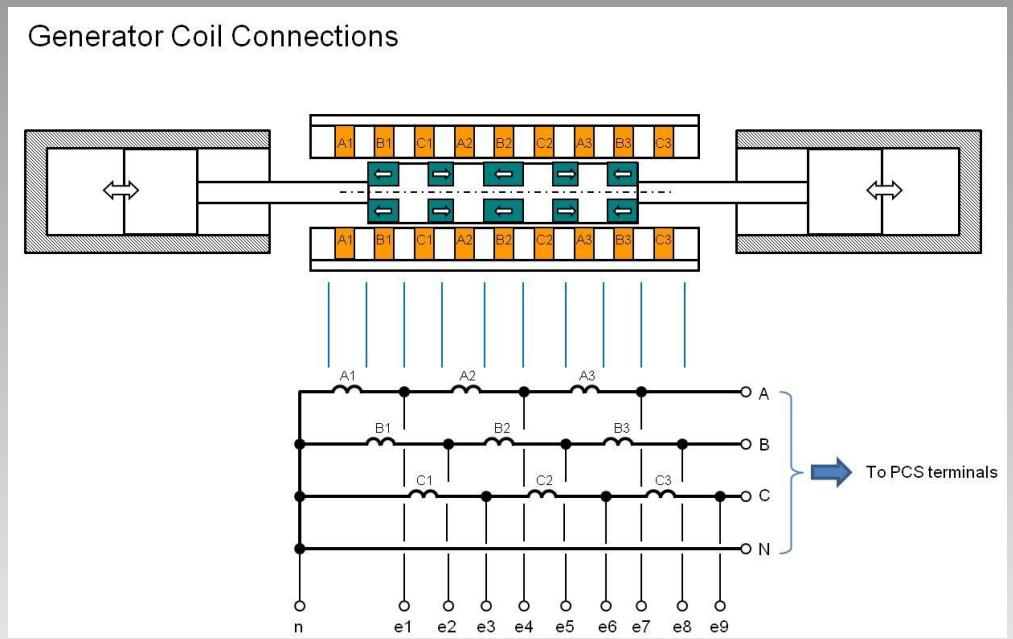

- ✓ 30Hz에서 최대출력은 4.6kW
- ✓ 효율은 91~96%의 효율 분포를 보임

# Control system

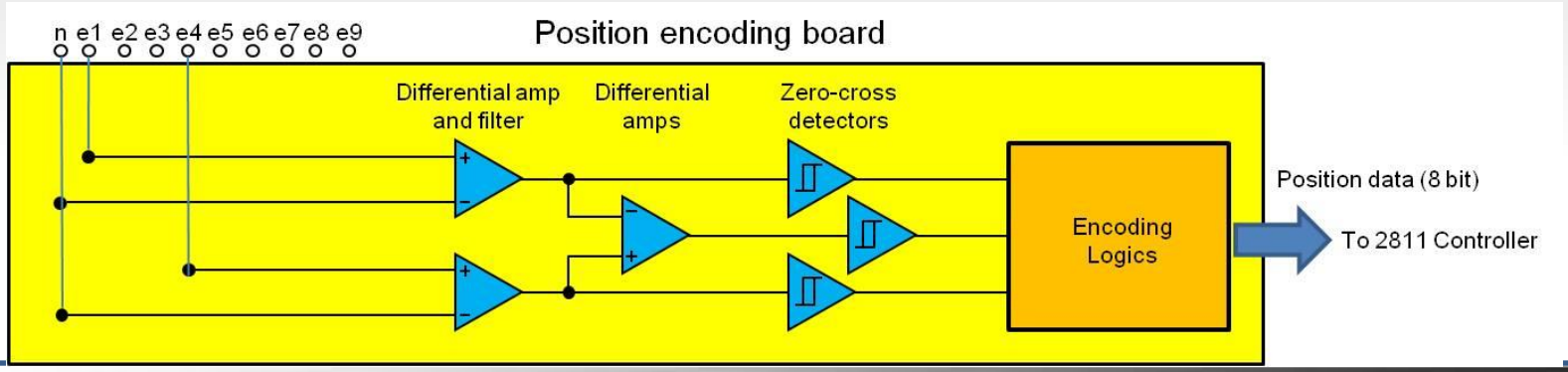
## ○ 엔진 운전 안정성 확보 방안

| 구분 | 2단계 | 3단계 |
|---|---|---|
| 엔진제어 신호 | 리니어 엔코더에 의한 위치검출 | 실시간 signal 출력 |
| 제어방법 | 위치신호에 의한 Feedback | 정밀제어 알고리즘에 의한 예측제어   |
| 흡입공기 공급 | 자연흡기 | 일정압력 과잉공기 공급 |

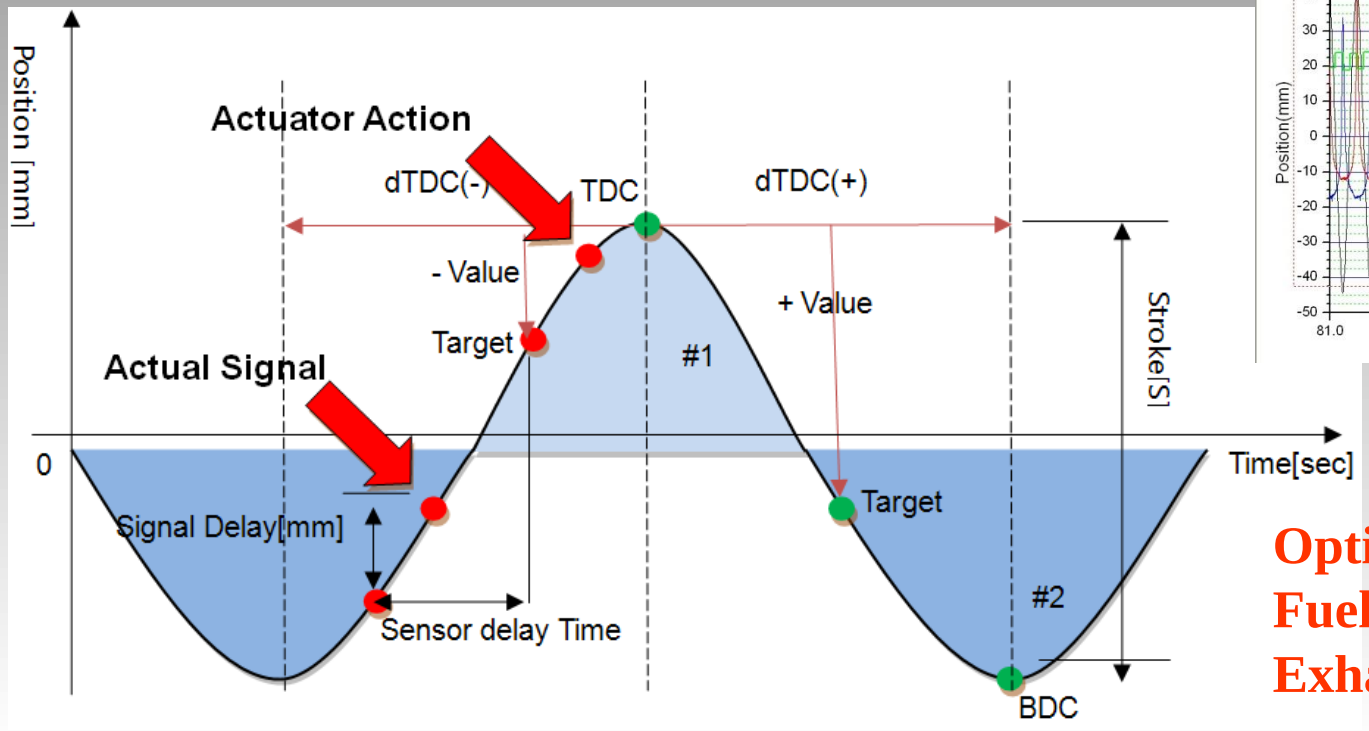
# ○ 포지션 인식 알고리즘

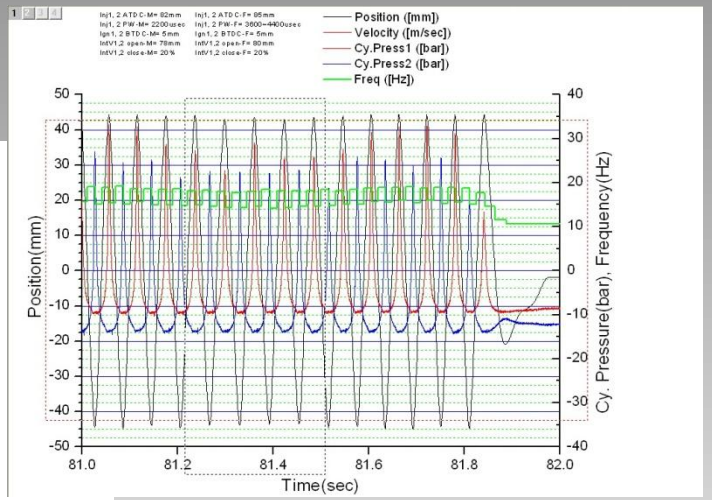



- Stator 코일 별 신호선 장착
- 파형 정제, 포지션 신호로 인코딩
- 발전전류 신호를 제어신호로 활용



# ○ 엔진 흡배기 및 연소 제어 최적화

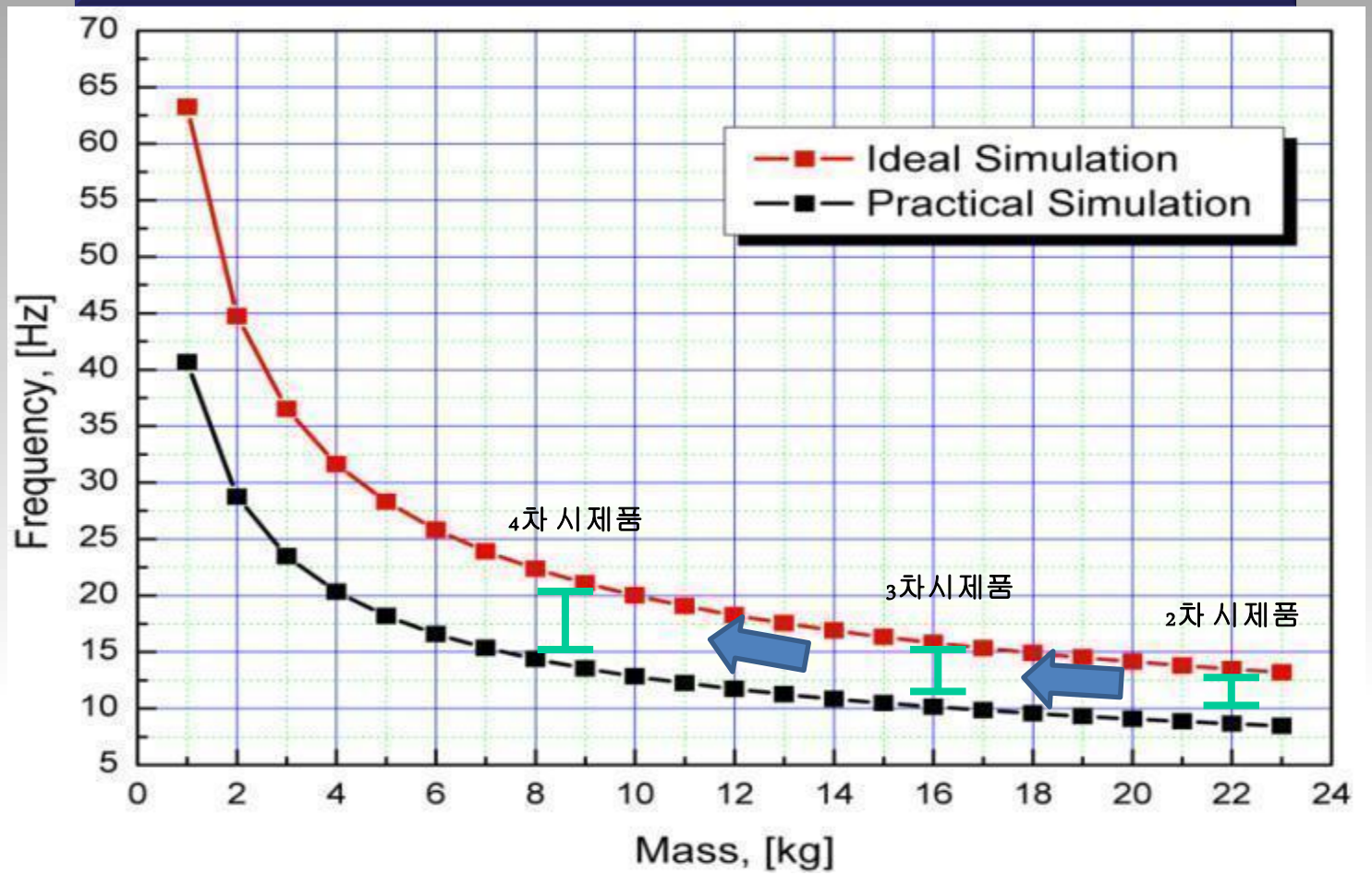


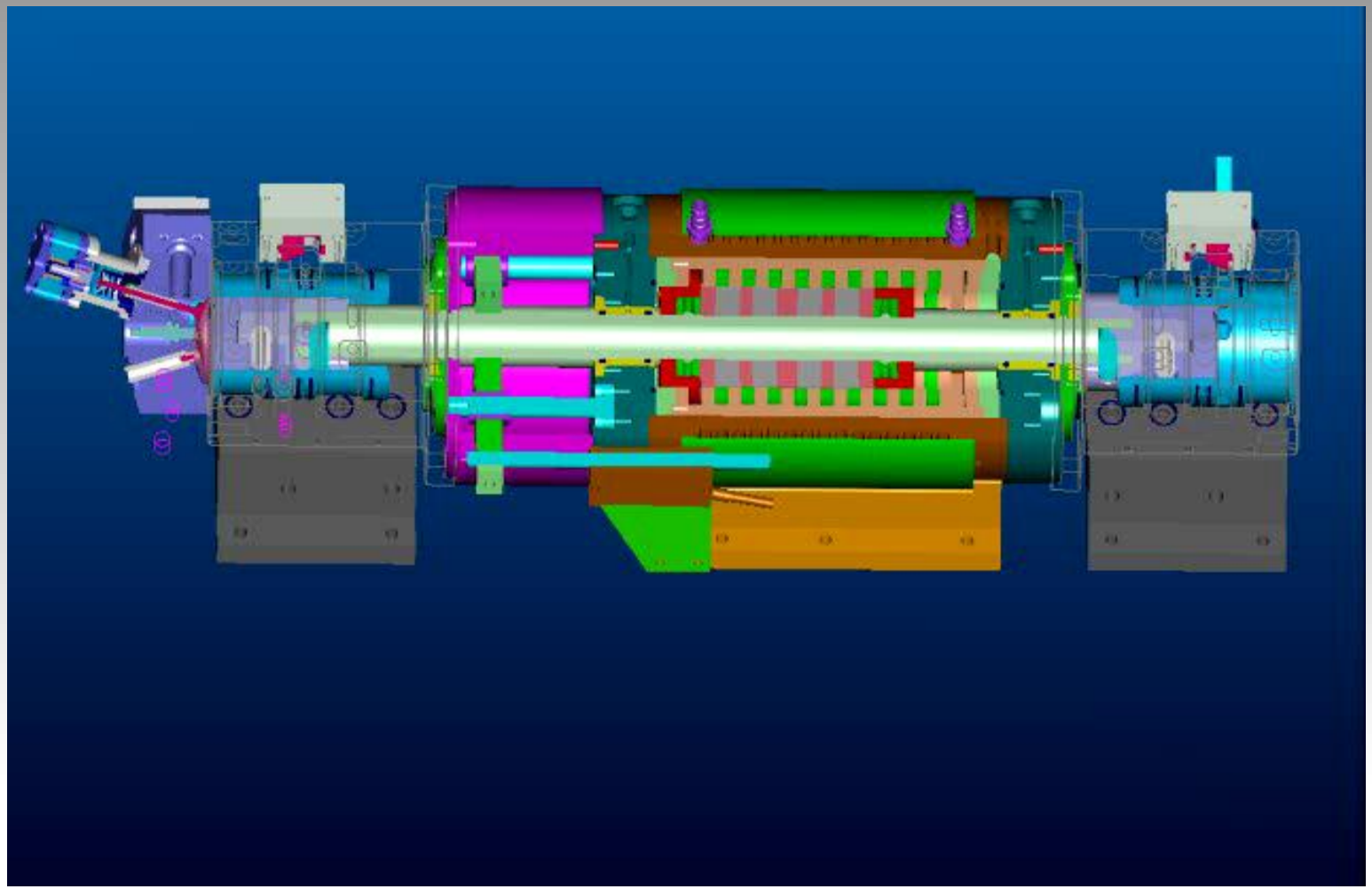

**Optimization of Air Intake, Fuel Injection, Spark Ignition, Exhaust, Position, etc.**

# System Down sizing

## 무버 중량 – 시스템 적정 주파수 Simulation

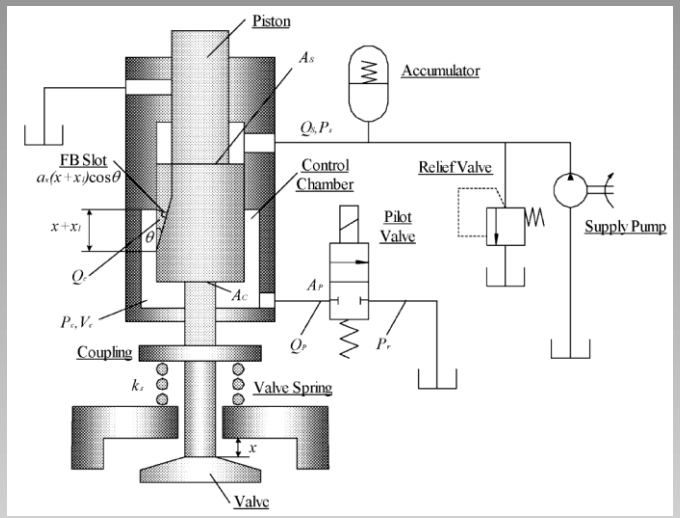


# ○ 구조 해석

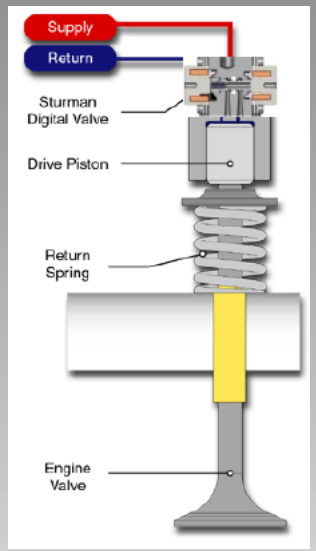


# ○ 캠리스 밸브 구동방식 검토

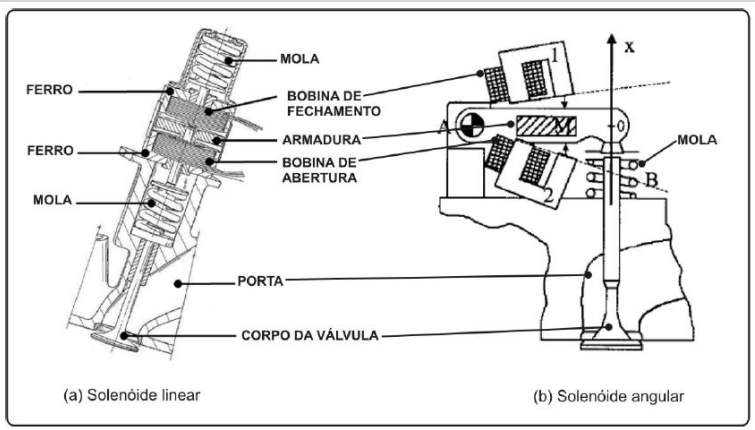
EHV_엔진텍



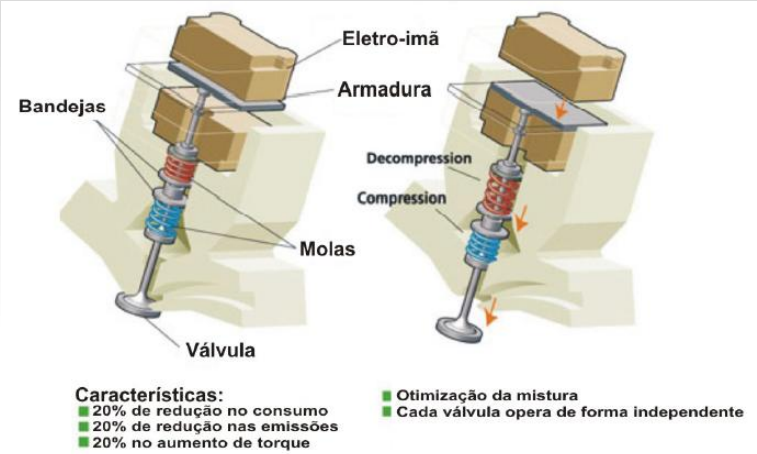

3 Port EHV_Yokohama Univ.




EHV_Sturman

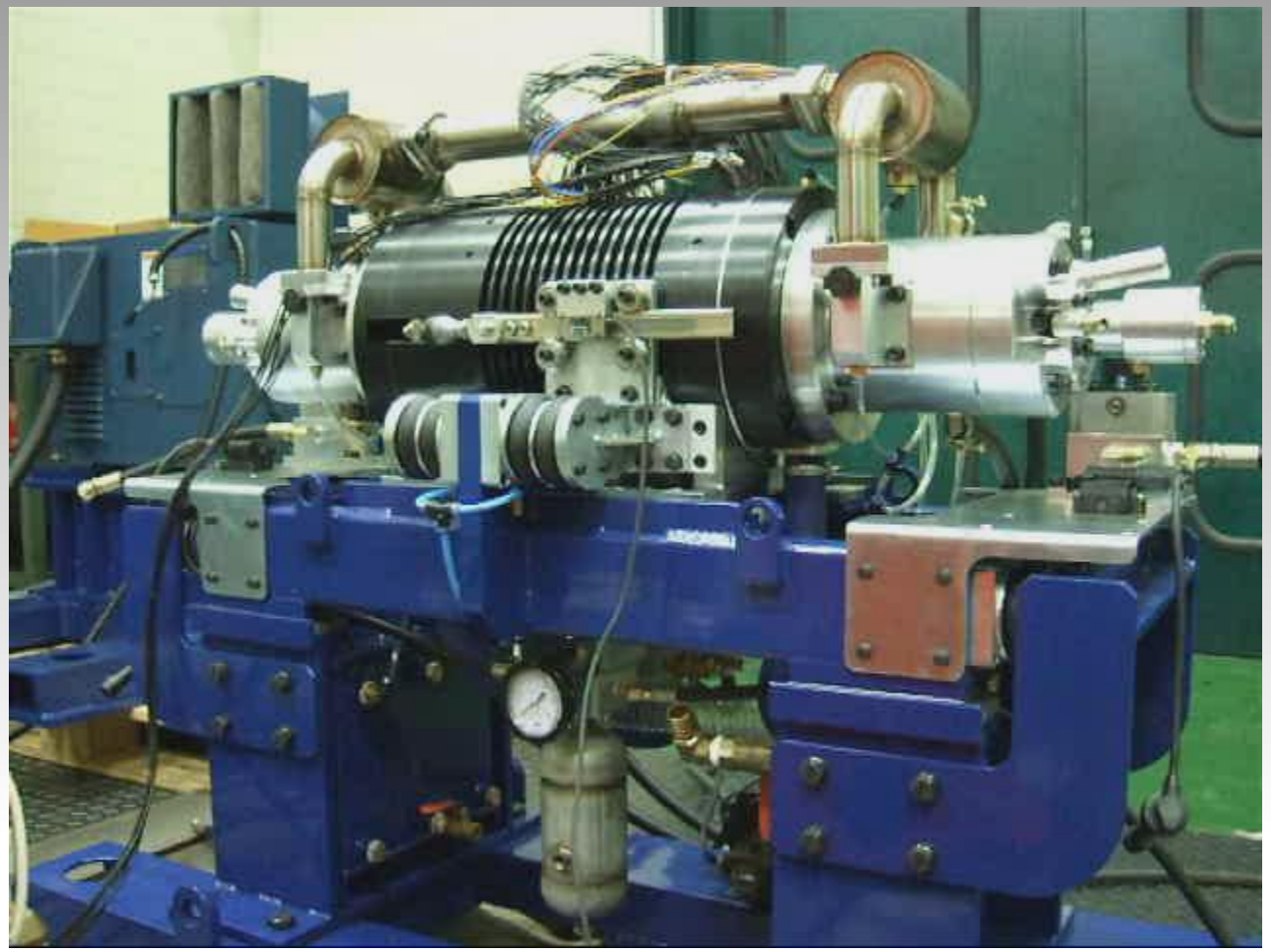



EMV_Chladny;Ronchi




EMV_Valeo

# 시스템 개발 결과

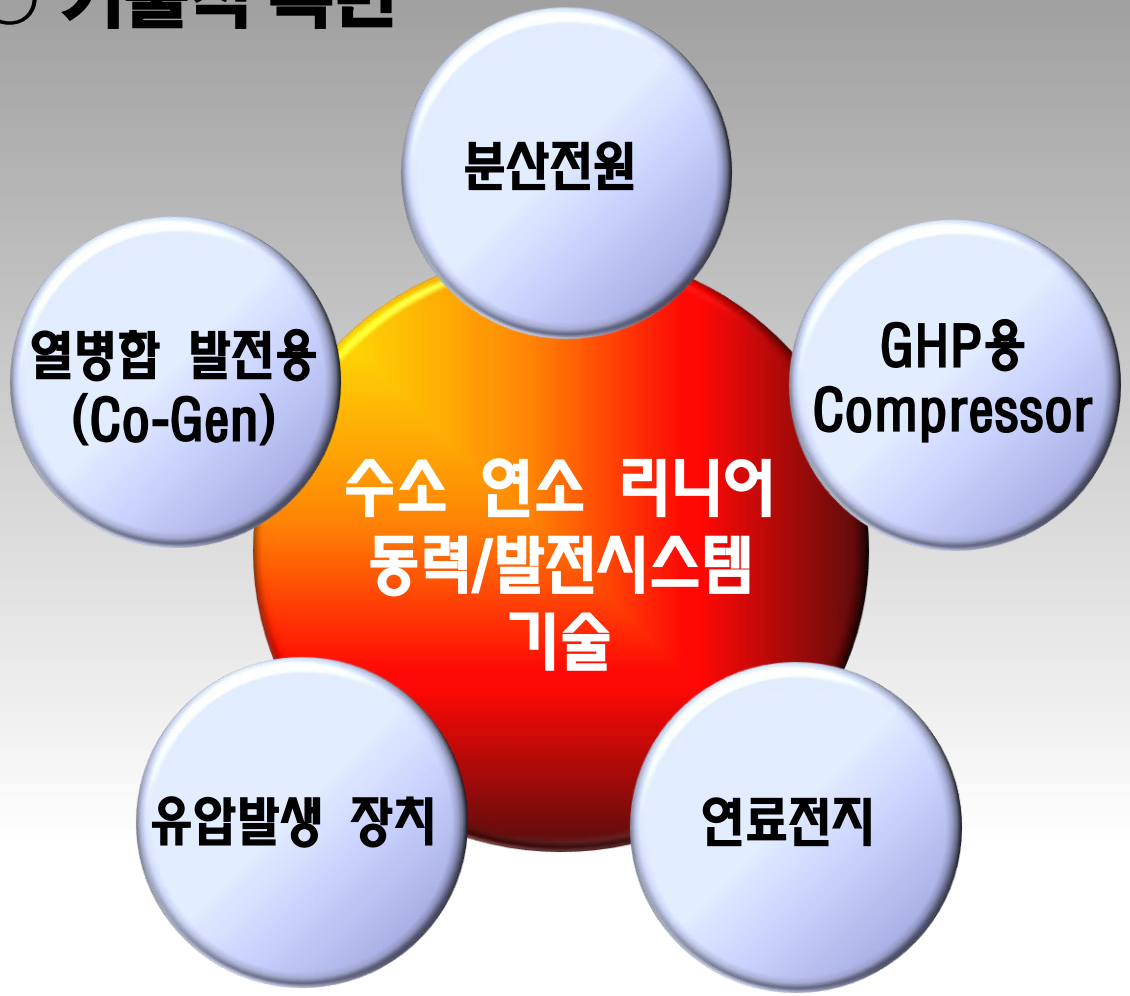


# 시스템 효율 비교

| | 1 kW | 5kW | | | |
|---|---|---|---|---|---|
| Fuel | CNG | Hydrogen | | | |
| Scavenging | Loop | Reverse Uni-flow | | | |
| Stage | - | 2nd stage | Combustion Opimized | Oscillation Optimized | Lightweight Mover |
| Stroke | -37~37 | -45.08 ~ 44.68 | -43.02 ~ 43.68 | -44.3 ~ 44.9 | -44.5 ~ 44.1 |
| Ignition | BTDC 11mm | BTDC 5mm | BTDC 29 mm | BTDC 1mm | BTDC 1mm |
| Frequency | 13 Hz | 17.5 Hz | 11.8 Hz | 19.8 Hz | 20.5 Hz |
| Fuel amount | 0.15 g/sec | 0.152 g/sec | 0.06 g/sec | 0.27 g/sec | 0.23 g/sec |
| Electronic Power | ~220 W | ~2.37 kW | ~1.3 kW | 4.7 kW | 4.8 kW |
| Efficiency | $\eta_i$ = 4.17 % | $\eta_i$ = 21.84 % | $\eta_i$ = 31.7 % | $\eta_i$ = 47.3 % | $\eta_i$ = 50.3 % |

# 기대효과

## ○ 기술적 측면




## ○ 경제/산업적 측면

- 신 동력시스템의 개발 해외시장을 개척하여 수출주도산업 육성
- 분산형 전원 및 GHP용 동력시스템 국내산 대체
- 현용 내연기관에 일부 준용 가능하여 기존 기술개발과의 연계성 우수
- 에너지 수입비용 대폭 저감
- 수소에너지의 이용분야를 확대, 사용량 증가가 가능한 대체에너지 이용 동력시스템의 확보.
- 석유계 연료 의존성의 완화 및 안정적인 에너지원 확보.

# Thank you !!!