附件三 WDL 公司潤滑冷卻分析簡報

WDL

AAE2 Rotary Engine Design & Analysis Support

Oil System

July 2012

C Whelan

Contents

Overview & Objectives

- Overview:
  - MPI are developing a new rotary engine, designated AAE2
  - WDL are providing design & analysis support to this programme
  - A review of the lubrication system is one task in the programme
  - This report presents the work performed by WDL on the lubrication system
- Objectives:
  - Review benchmark engine design & operation
  - Evaluate basic lubrication requirements for a rotary engine
  - Investigate adaptation of the lubrication system for rotor cooling
  - Review oil-pump requirements
  - Assess potential advantages of an electric oil pump
  - Recommend design approach for AAE2 programme

Technical Approach

- There is only limited knowledge of rotary engine design & development, so the AAE2 programme included benchmarking & test measurements to support the design analysis
- The current MPI engine design relates closely to the original Wankel engine (NSU, F & S etc.) of the 1960s. All current UAV/kart/aircraft engines closely follow these original designs
- Design Benchmarking:
  - The AAOOO engine at MPI was analysed & tested
  - The Mazda RX-8 (Renesis) engine design & construction was analysed, making allowance for the different design & application (automotive vs. aerospace)
  - Review published technical literature from:
    - Mazda
    - NSU
    - Fitchel & Sachs
    - Daimler Benz
    - Curtiss Wright
- Baseline Testing:
  - Thermal & air/oil flow testing of the AAOOO engine
- Design Analysis:
  - Oil flowrates for lubrication & cooling
  - Rotor cooling
- This information allowed analysis of the best oil system & recommendations for the AAE2 design

Background & Benchmarking

Background: Suzuki RE-5 (1)

- Ref: SAE 770290
- Single rotor motorcycle engine, capacity 497 cc
- Water-cooled housing
- Plain bearings for shaft & rotors
- Rotor cooling by oil, shared with bearing lubrication system
- Separate oil supply to rotor seals (throttle/speed controlled pump)
- Additional rotor seals required for oil sealing

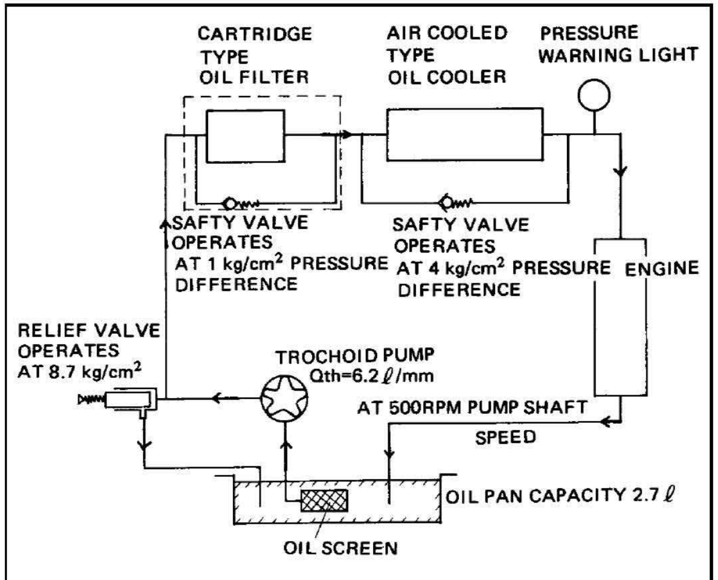
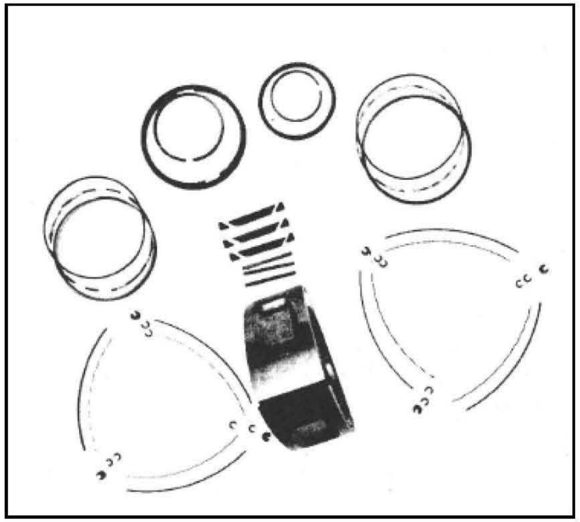
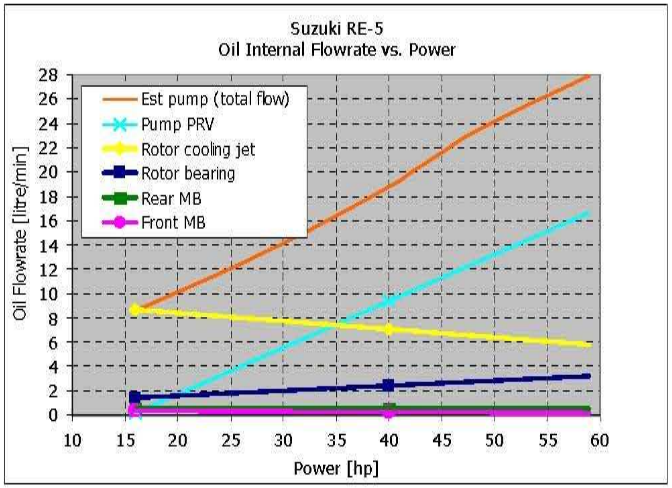


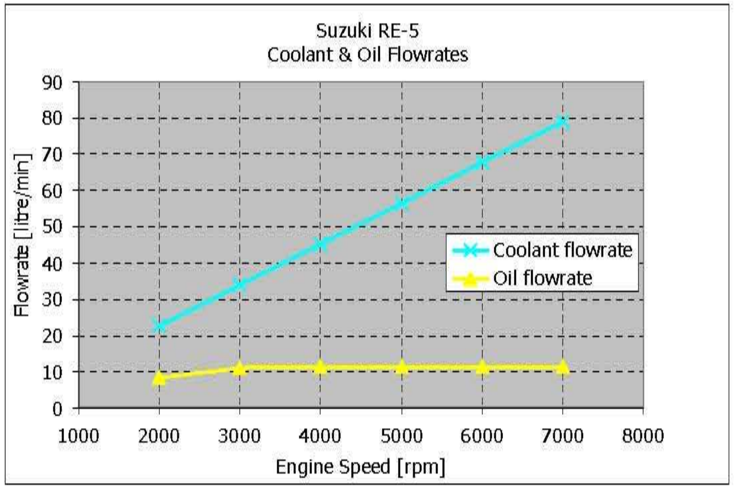
Fig. 18. Oiling system



Background: Suzuki RE-5 (2)

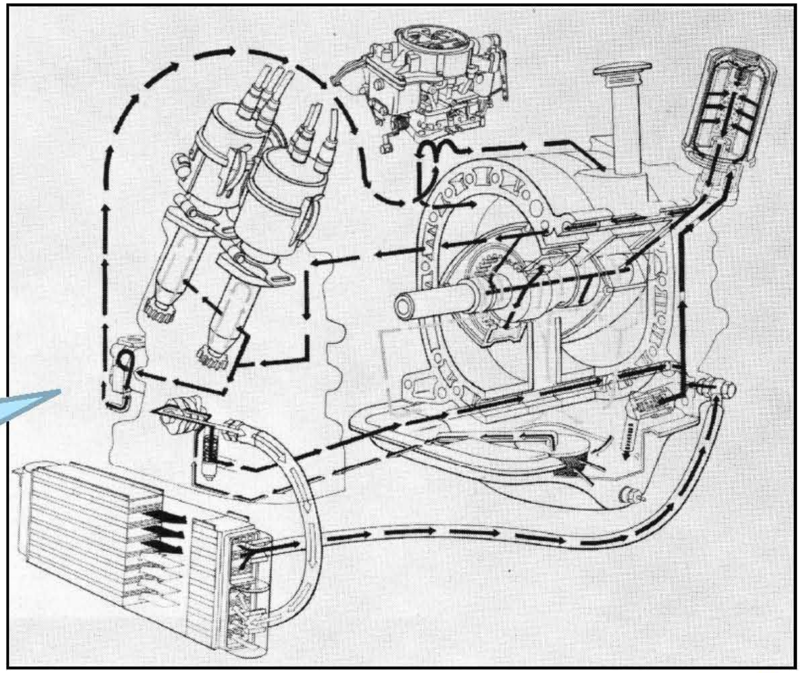
- Rotor cooling by oil, shared with bearing lubrication system
- Separate oil supply to rotor seals (throttle/speed controlled pump)
- Plain bearings, used so higher oil flowrates than for roller bearings (AAOOO)
- Oil flowrate approx. 11 l/min over speed range
- 6~8 l/min for rotor cooling, balance for bearing lubrication
- Specific rotor cooling flowrate is approx. 6 litre/hp h at max. power





Background : Mazda RX-8 (1)

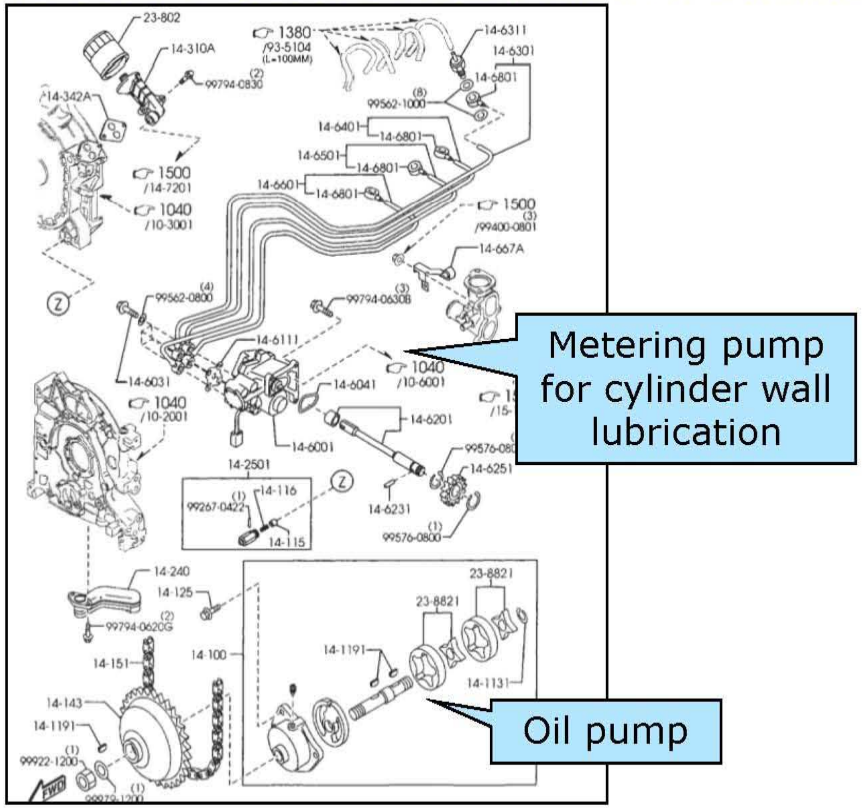
- Ref: SAE 2004-01-1790
- Twin rotor car engine, capacity 1308 cc
- Water-cooled housing
- Plain bearings for shaft & rotors
- Rotor cooling by oil, shared with bearing lubrication system
- Common oil supply to rotor seals (throttle/speed controlled pump)



NOTE: 10A engine system shown, but similar to RX-8

Background: Mazda RX-8 (2)

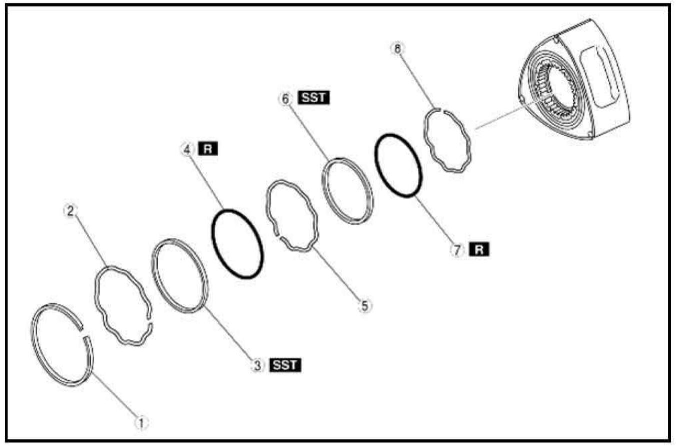
- Complex oil metering pump for seal lubrication
- Oil metering is a function of speed. throttle position & crankcase pressure

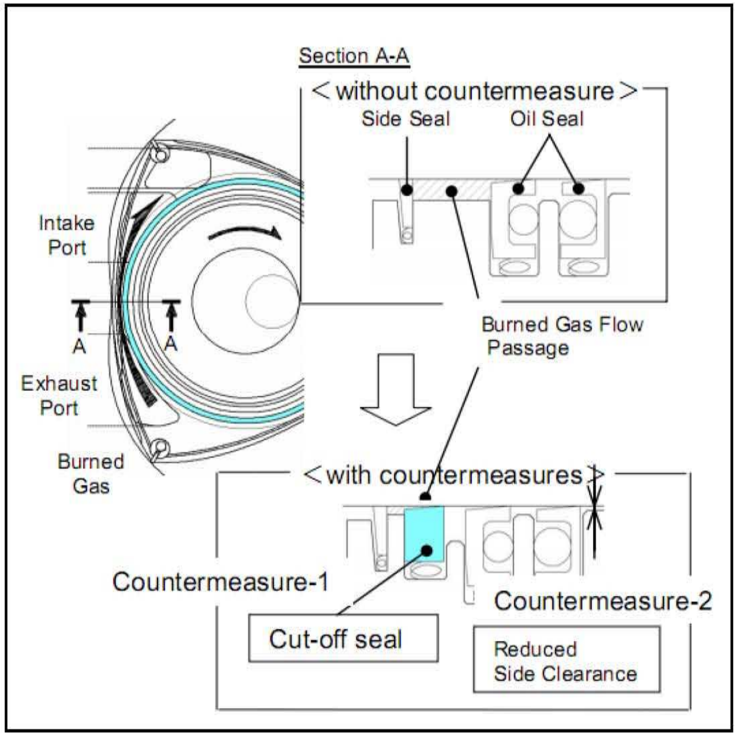


Background: Mazda RX-8 (3)

- Full oil cooling requires rotor oil sealing

- Example (**Mazda**)
- There are 3 oil seals on each side of the rotor
- The oil seals each have 3 pieces
- The cut-off seal has 2 pieces (NOT required with peripheral port engine)



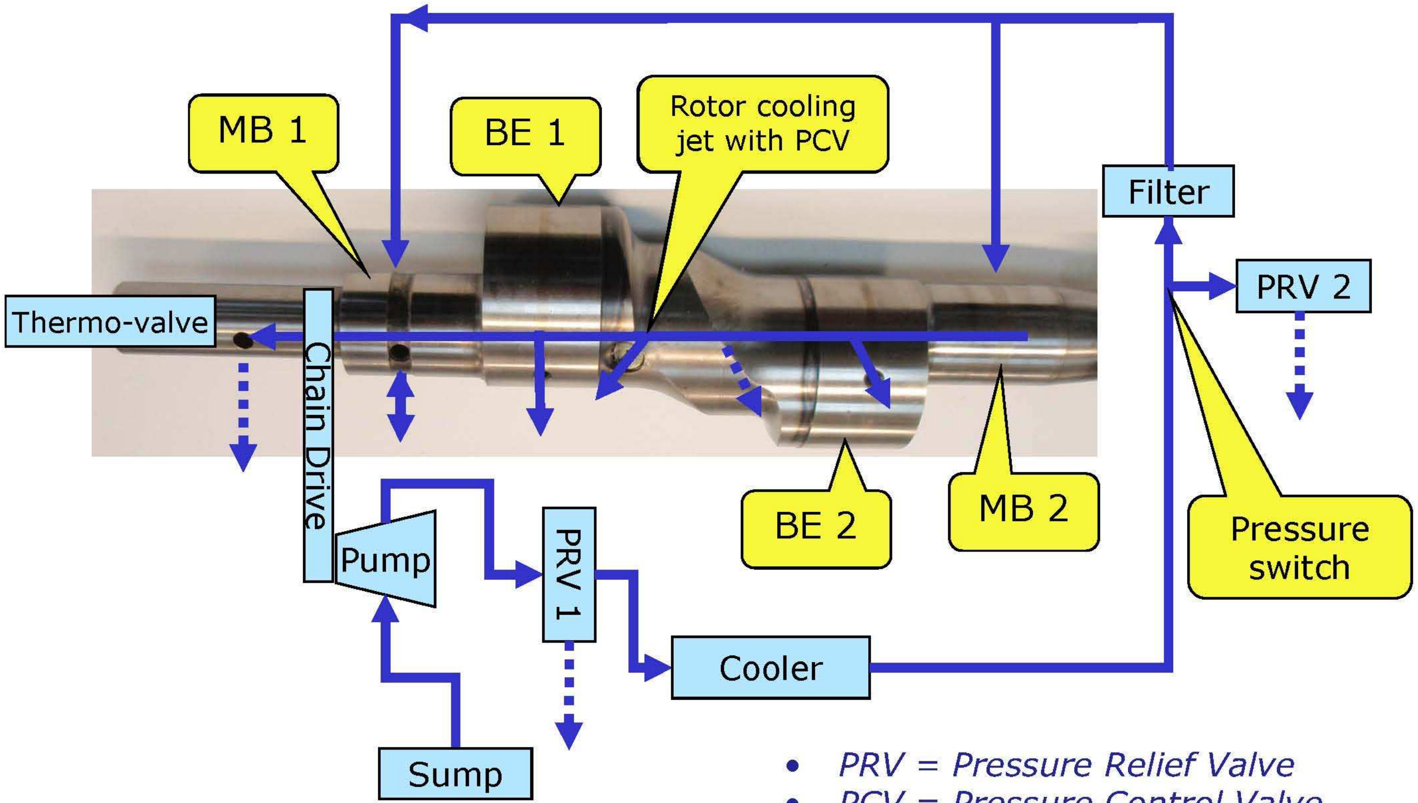


Background: Specific Oil Flowrates (1)

- Different designs have different oil flowrates
- We are most interested in the cylinder oil flowrate (rotor seal lubrication)
- A basis for comparison is specific flowrate: cc/hp h
- From the study we found:
  - AAOOO:
    - Total spec. flowrate (bearings + seals): 10.2 cc/hp h
    - Cylinder (rotor seals): max. 1.5 cc/hp h
    - Flowrate is proportional to speed only
  - Suzuki RE-5:
    - Cylinder (seals): max: 2.5 cc/hp h
    - Flowrate is proportional to speed & throttle angle
  - Fitchel & Sachs KM-914:
    - Total spec. flowrate (bearings + seals): 6.2 cc/hp h
    - Cylinder (seals): max: 6.2 cc/hp h
    - The rotor is cooled by engine combustion air, so ALL the oil (bearings & seals) goes into the cylinders
    - Flowrate is a fixed proportion of fuel flow (approx. 1:40, pre-mixed)
  - Mazda RX-8:
    - Cylinder (seals): MIN: 0.25 cc/hp h
    - NOTE: max. value not known
    - Flowrate is proportional to speed, throttle angle & crankcase pressure

Benchmark: Mazda RX-8 (1)

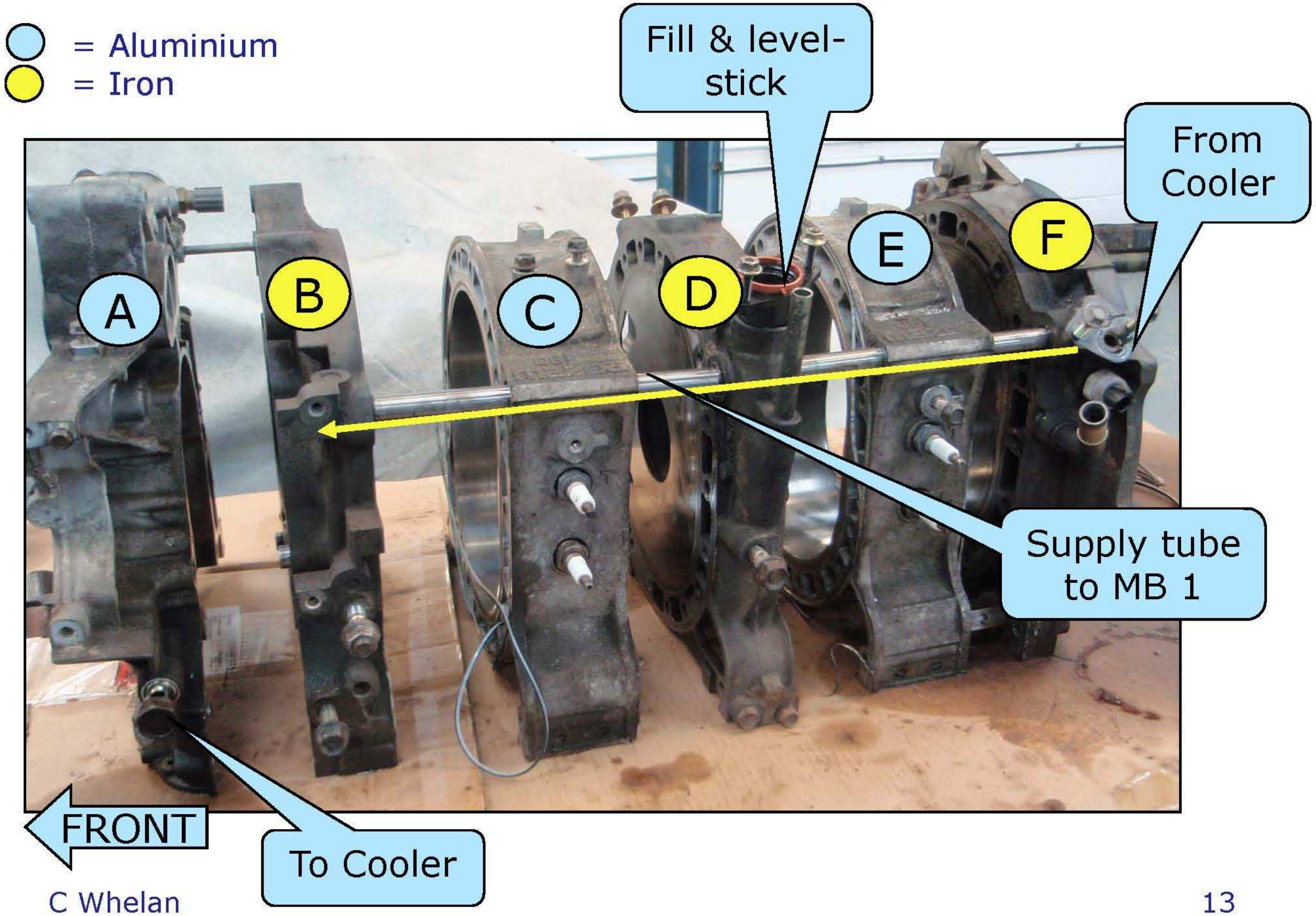
- System schematic



- *PRV = Pressure Relief Valve*
- *PCV = Pressure Control Valve*

Benchmark: Mazda RX-8 (2)

= Aluminium (blue circle)
= Iron (yellow circle)



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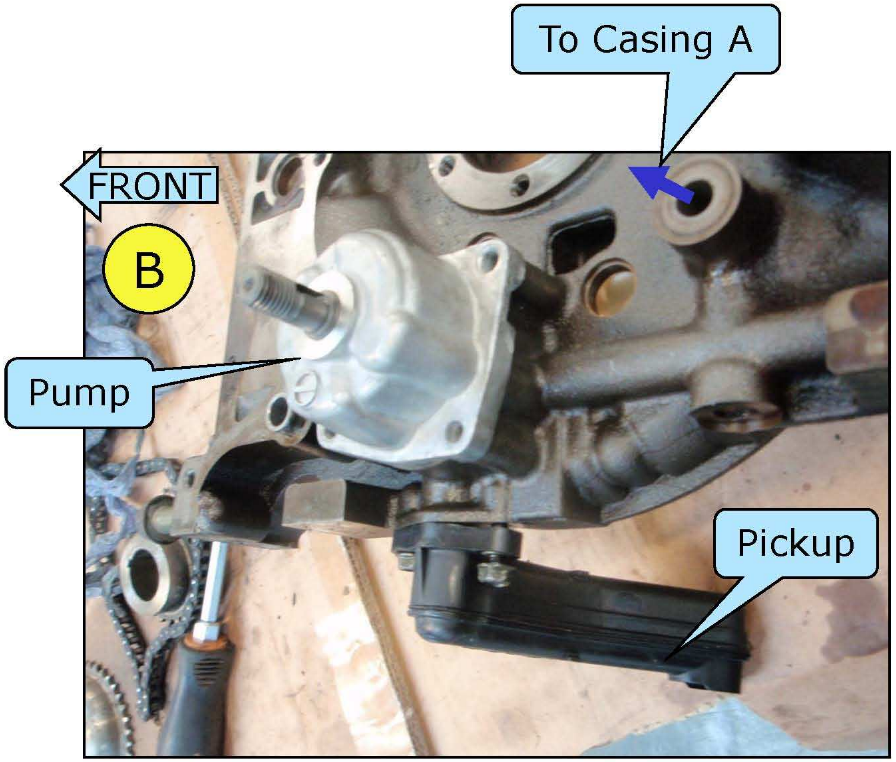
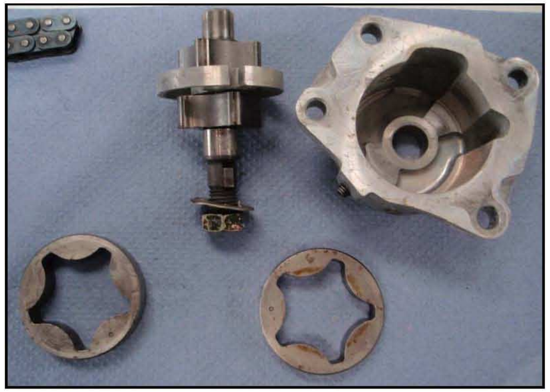
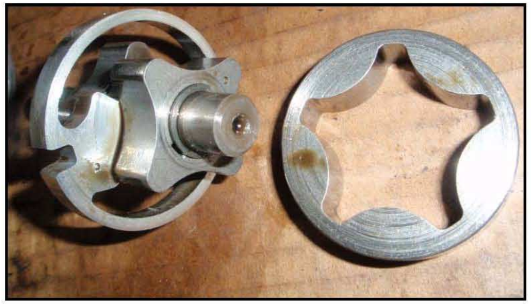
Benchmark: Mazda RX-8 (3)

- Twin rotor pump
- Speed ratio = 24/36 x shaft speed







Benchmark: Mazda RX-8 (4)

- Thermo-valve is installed in the end of the main shaft & is located by the front pulley bolt
- When oil is cold:
  - Thermo-valve is ‘open’
  - Oil leaks from main shaft
  - Pressure inside main shaft is reduced so there is no rotor oil jet flow (jets have pressure control valve)
  - Pressure at rotor bearing is also reduced
- When oil is hot:
  - Thermo-valve is ‘closed’
  - Main shaft is sealed
  - Pressure increase insider the shaft & oil flows through the rotor jets
  - Pressure at rotor bearing is also increased
- *Opening temperature to be checked*
- *Rotor oil jet to be checked (see rotor cooling report)*

AAOOO Lubrication System

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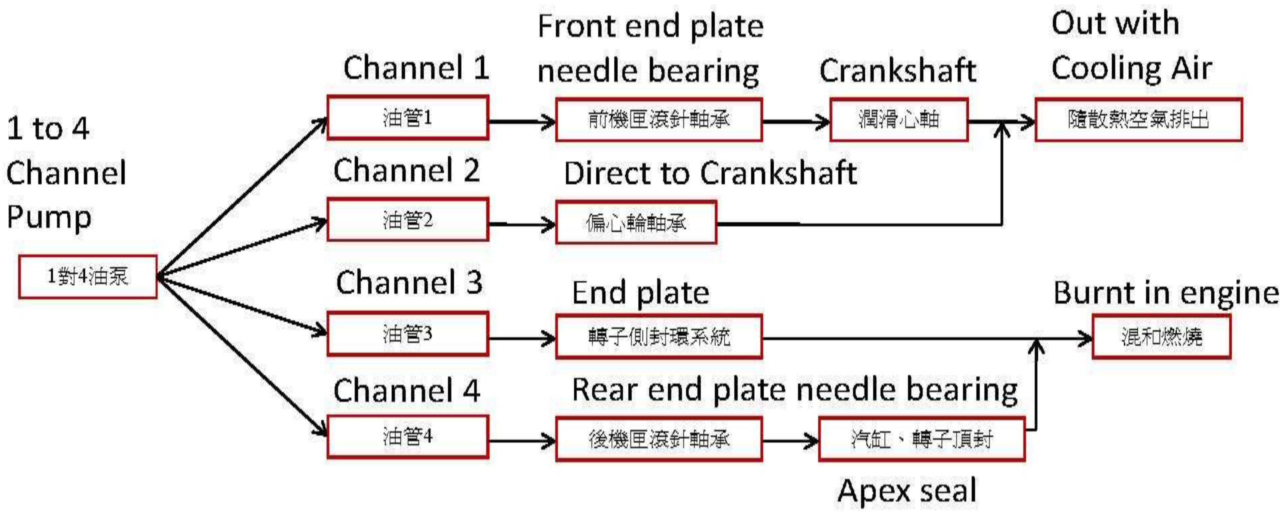
AAOOO: Oil Distribution Layout



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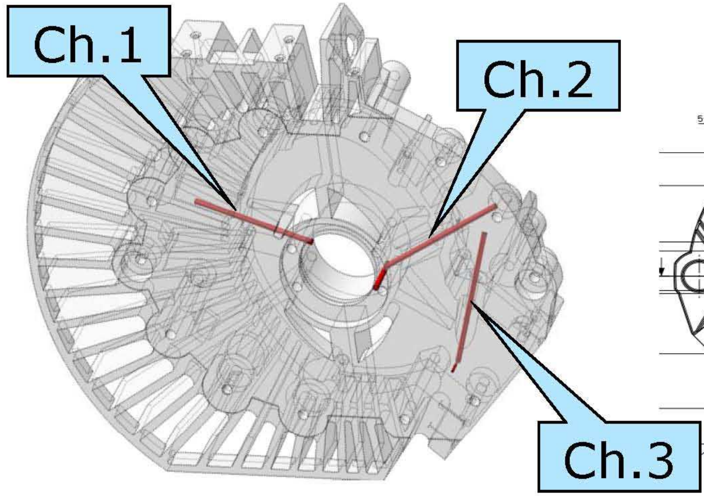
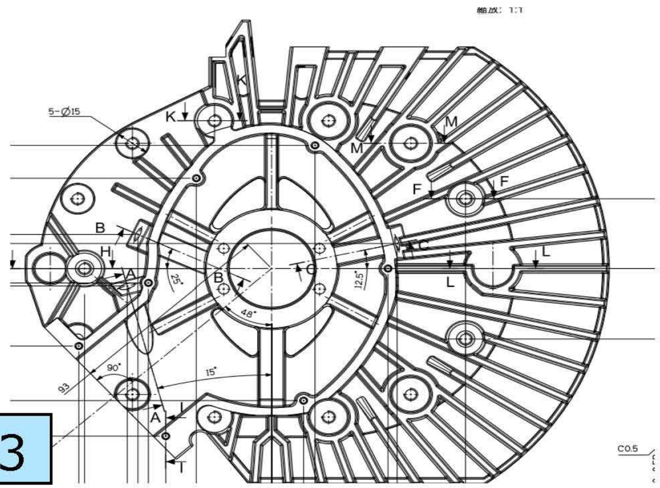
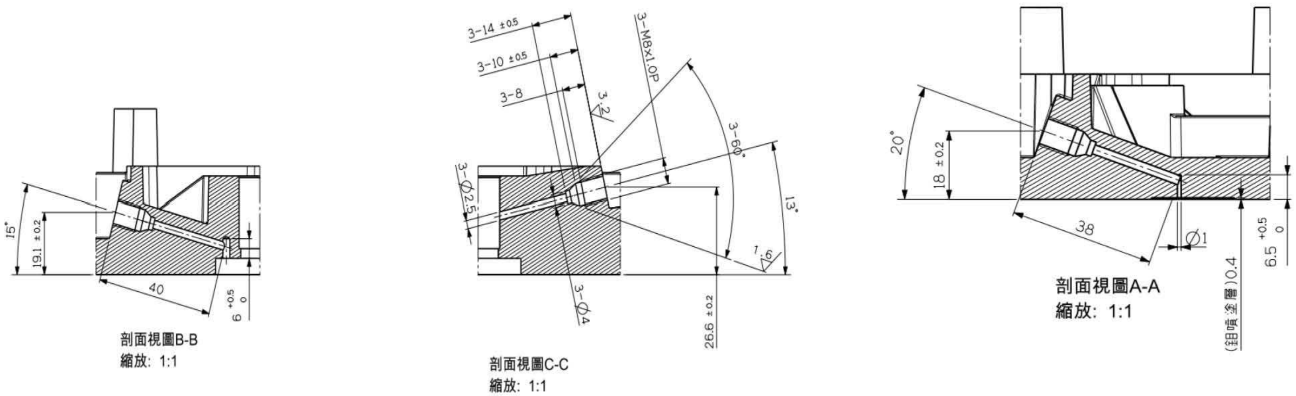
AAOOO: Front Cover Oil Distribution







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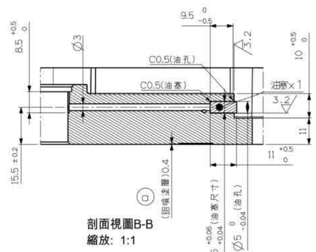
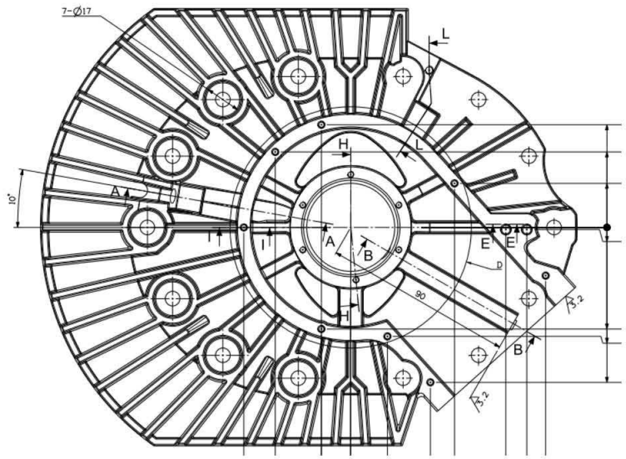
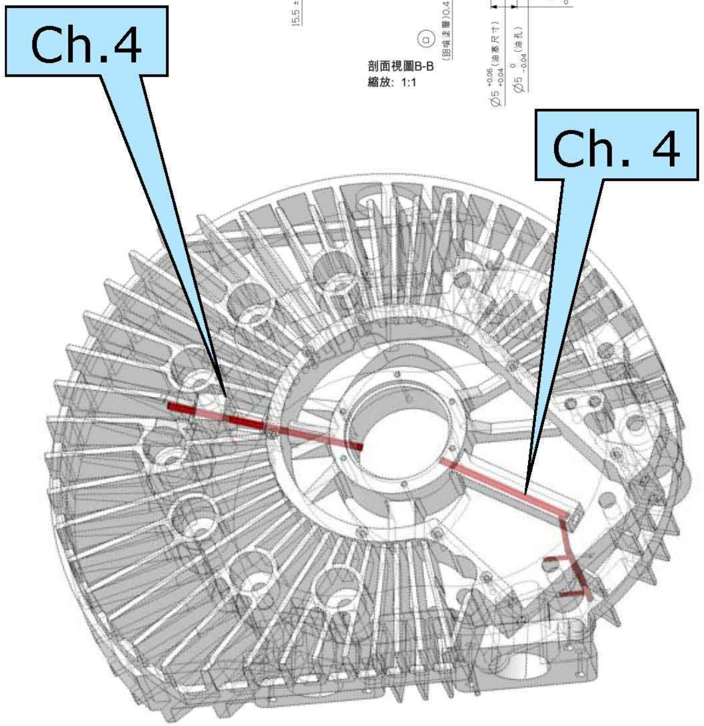
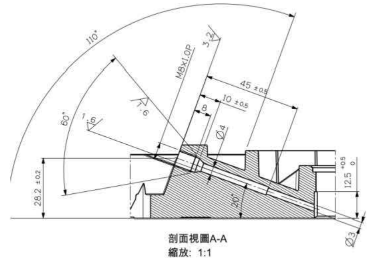
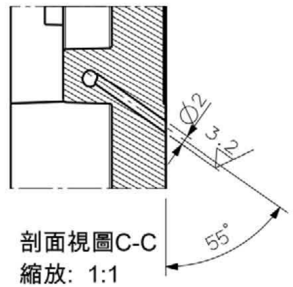
AAOOO: Rear Cover Oil Distribution



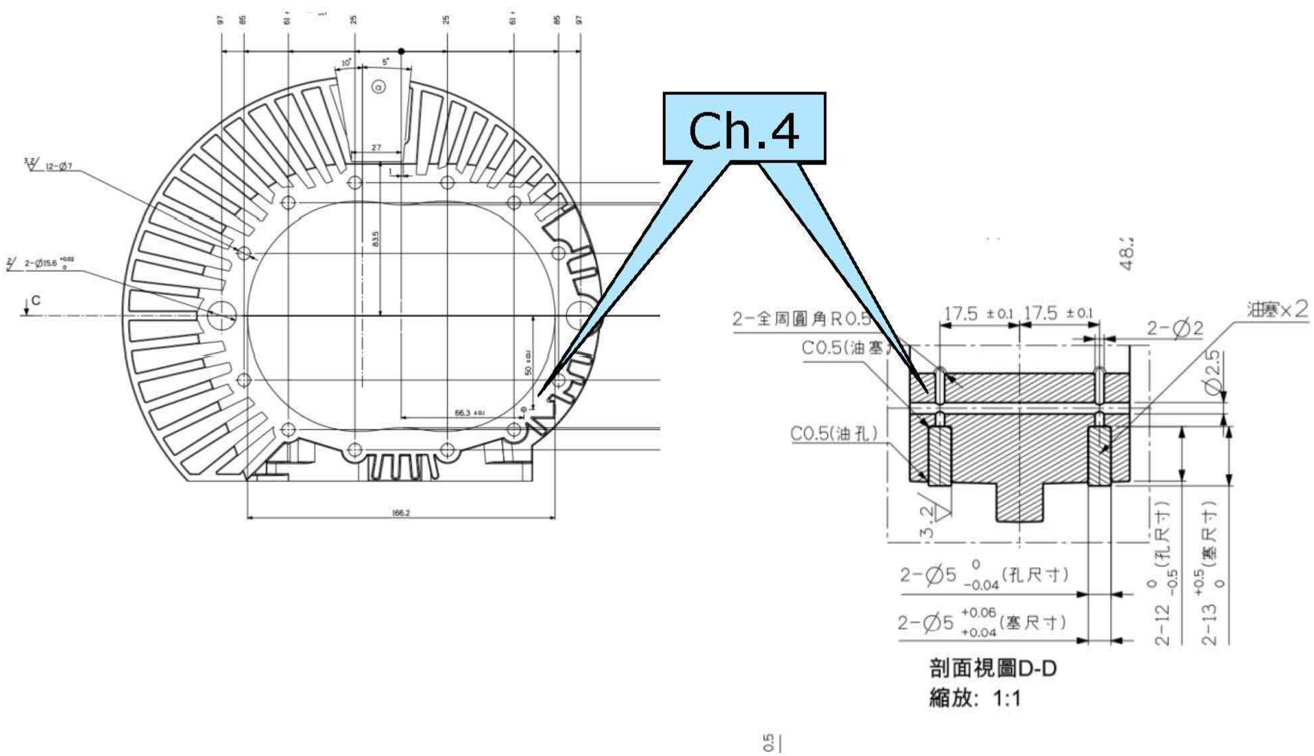








AAOOO: Housing Oil Distribution



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AAOOO: Flow Distribution & Pump

測試項目 TEST ITEM	流量測試		測定結果 TEST RESULTS	☑OK ☐NG
圖號 DWG.NO	B1Z0	機種 MODEL		
品名 DESIGNATION	OIL PUMP ASS'Y	測試日期 DATE	2010/10/22	
基本條件 CONDITIONS		試驗方法 TEST METHOD		

流量測試機

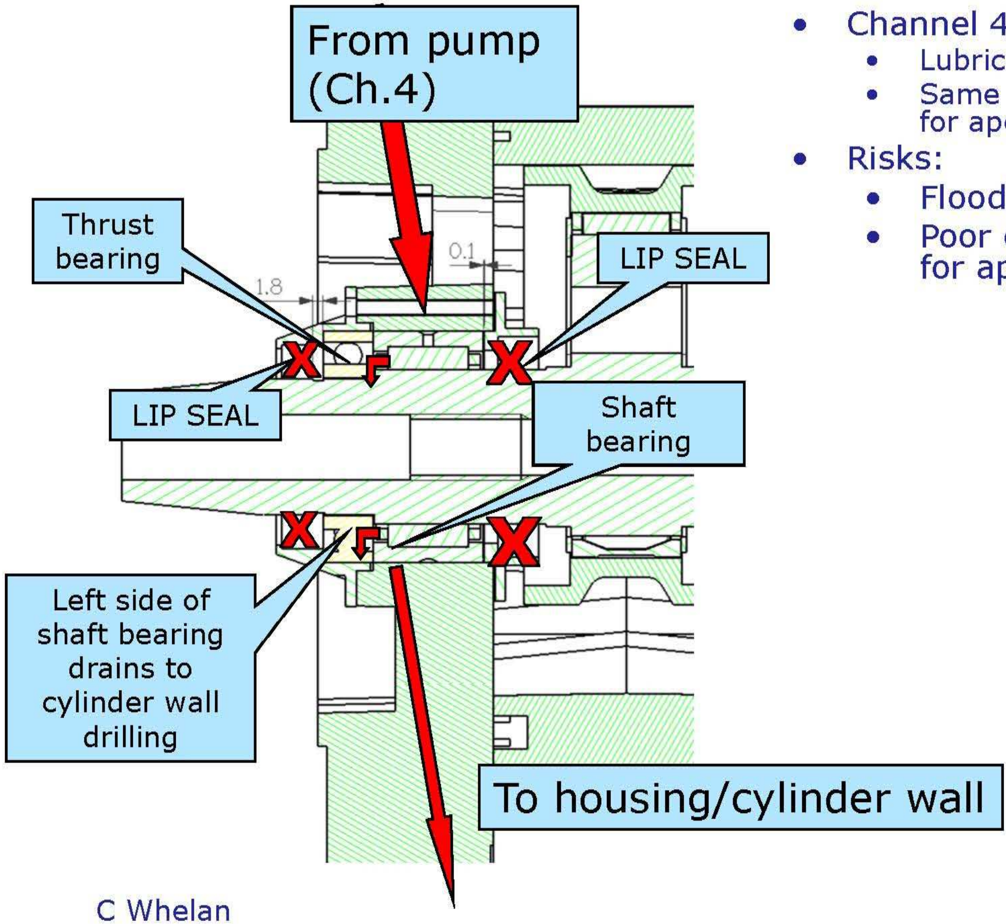
試驗結果
TEST RESULTE

Engine rpm
Pump rpm

NO / 項目	MIKUNI 樣品 總重:195g							
	eng 7000 / pump 4083rpm		4000 / 2333rpm		6000 / 3500rpm		5000 / 2917rpm	
	重量 g/40min	流量 cc/hr	重量 g/70min	流量 cc/hr	重量 g/23.33min	流量 cc/hr	重量 g/27.99min	流量 cc/hr
1 (CH 1)	83.43	147.29	83.51	84.28	41.72	126.16	41.70	104.98
2 (CH 3)	12.29	21.75	12.66	12.82	6.14	18.56	6.18	15.55
3 (CH 4)	13.90	24.56	13.74	13.87	6.98	21.11	7.01	17.64
4 (CH 2)	82.24	145.28	82.61	83.33	41.18	124.50	41.29	103.95

COMMENT:
1)Ch.1: HIGH flow to FRONT bearing
2)Ch.4: LOW flow to REAA bearing

AAOOO: Rear Bearing Lubrication



- Channel 4 oil feed:
  - Lubricates bearing
  - Same oil then enters housing for apex seal lubrication
- Risks:
  - Flooding of rear bearing
  - Poor oil supply to housing for apex seal lubrication

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AAOOO Bearing Friction & Lubrication

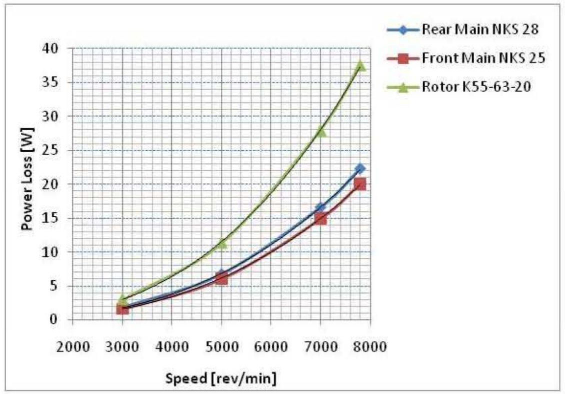
- Roller bearings have low friction
- AAOOO friction was calculated from dynamic loads & INA design guidelines
- Very small quantities are required for lubrication
- Much more oil flow required for full cooling
- Front bearing: Flowrate too high for much oil for lubrication, too little for cooling
- Rear bearing: Flowrate close to lubrication requirement
- Shaft bearing: Flowrate too high for much oil for lubrication, too little for cooling (*)

(*) Note: Oil for shaft bearing & gear lubrication splashes from front bearing & a separate supply (Ch.2)

Bearing		% rated	Front Main				Rear Main				Rotor			
Model	INA		NKS 25				NKS 28				K55-63-20			
Friction power & oil flowrate														
f (friction coefficient)	[-]		0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Mr (friction torque)	[Nmm]		25	20	12	5	27	23	13	6	46	38	22	10
Nr (friction power)	[W]		20	15	6	2	22	17	7	2	38	28	11	3
oil dT 9target)	[degC]		30	31	32	33	30	31	32	33	30	31	32	33
oil flowrate	[litre/min]		0.024	0.017	0.007	0.002	0.026	0.019	0.007	0.002	0.044	0.032	0.013	0.003
Oil flowrate for 100% cooling	**[cc/h]**		**1421**	**1024**	**402**	**104**	**1579**	**1137**	**447**	**116**	**2661**	**1917**	**753**	**195**
AA000	*[cc/h]*		*147*	*132*	*94*	*57*	*25*	*22*	*16*	*10*	*292*	*262*	*187*	*112*

Oil flow required for 100% cooling

Measured flows



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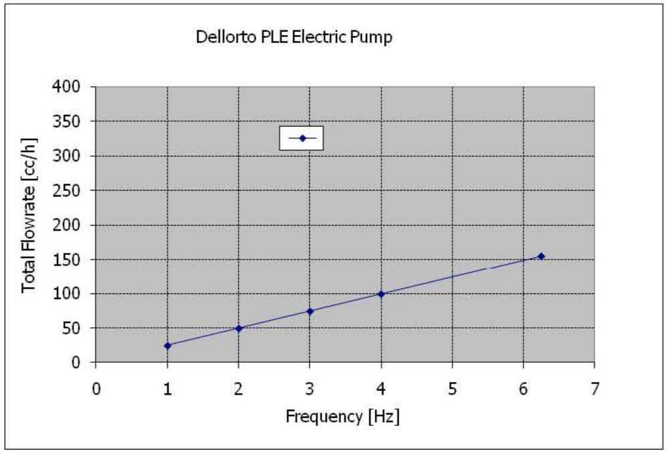
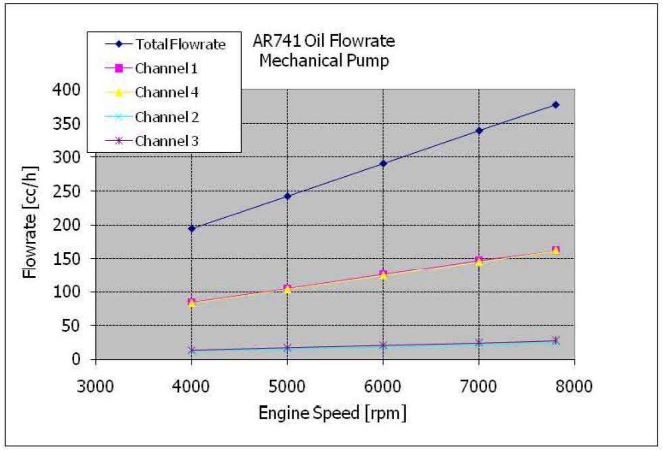
AAOOO Flow Distribution & Pump

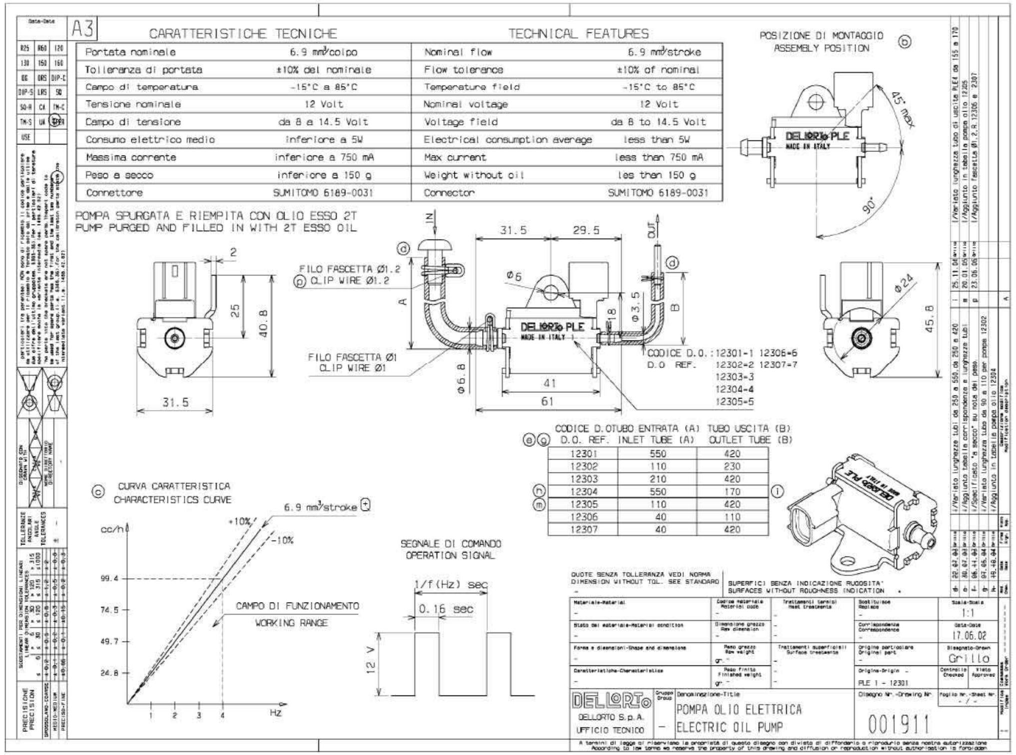
- Oil flow distribution seems unbalanced
- Front bearing flowrate is too high
- Shaft bearing flowrate, by splash, may be too high
- Rear bearing & housing flowrate (rotor apex seal lubrication) appears low
- The individual flowrates should be revised, & the total oil flowrate reduced
- If the total oil flowrate, at max. speed, can be less that ~150 cc/h, then an ECU-controlled electric oil can be considered





Electric Oil Pump Example

- Dellorto PLE
- Solenoid piston pump
- 12V, PWM controlled
- Max. delivery: 150 cc/hour
- Weight: 150 g



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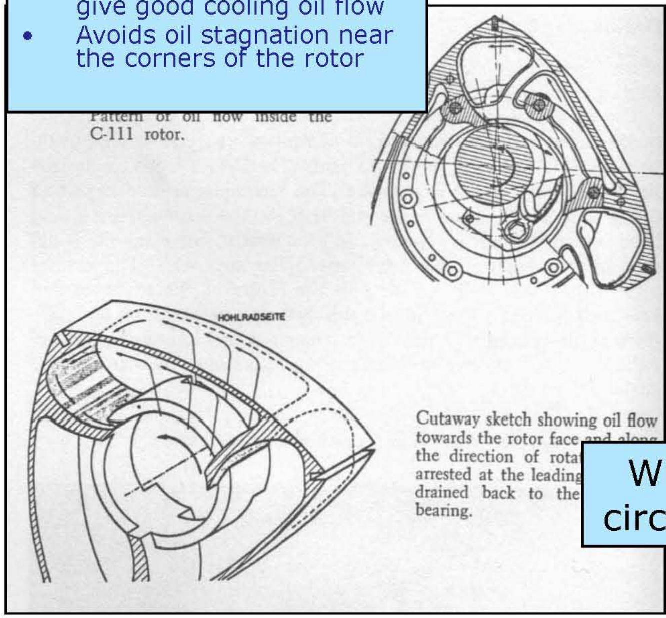
Rotor Cooling by Oil

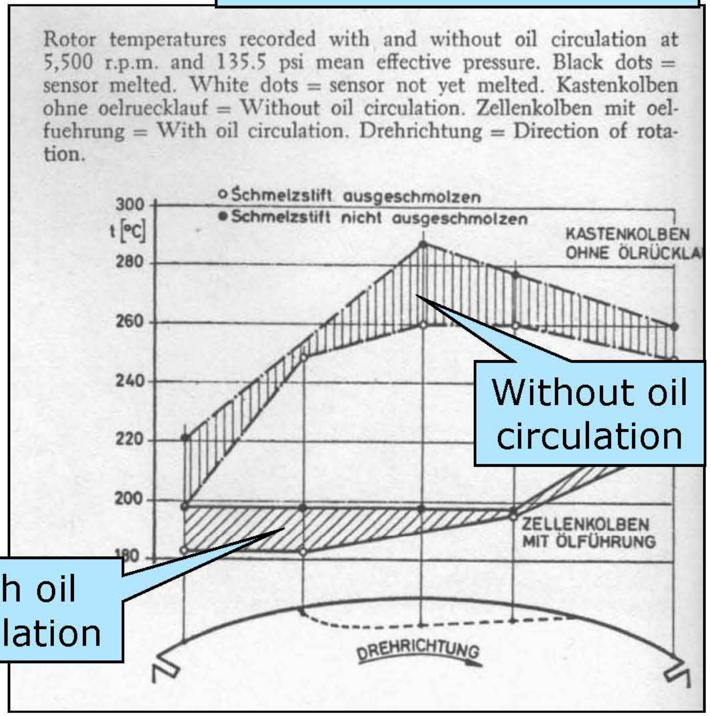
Background: Rotor Oil Cooling

- Full oil cooling will:
  - Improve overall internal cooling
  - Eliminate oil loss to atmosphere
  - Require addition of rotor oil seals

- Example (**Daimler-Benz**)
- Internal rotor design to give good cooling oil flow
- Avoids oil stagnation near the corners of the rotor

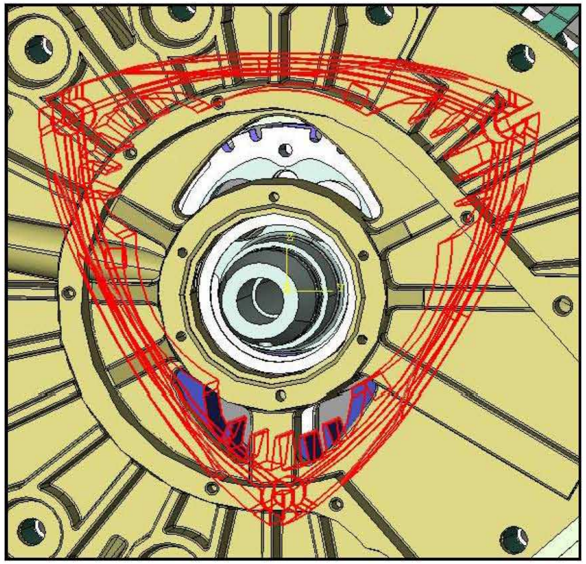


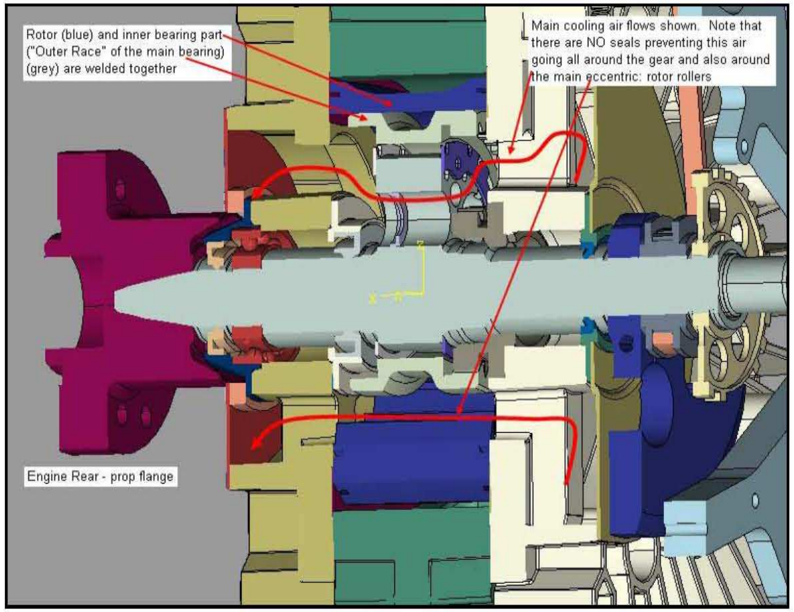
- Example (**Daimler-Benz**)
- Rotor surface temperature with & without oil circulation system



AAOOO: Rotor Cooling

- Cooling is by air passing internally through the rotor
- Oil does not contribute to the cooling, only lubrication





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