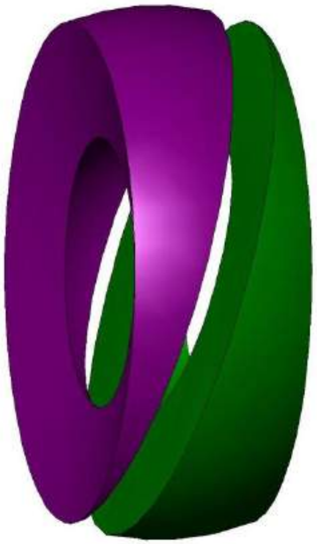


Wobble / Nutating Plate Pumps

Project(s) review

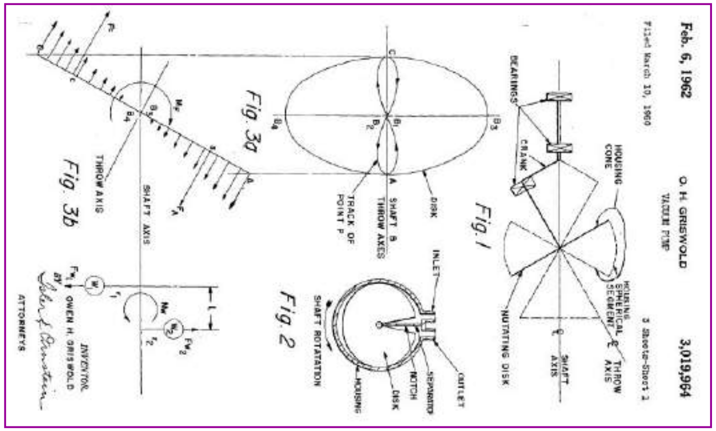
By Lindsay Dalziel, Design Director of

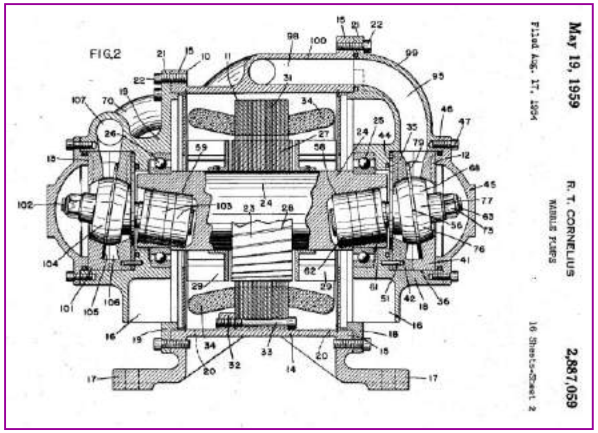
Design SMART® Ltd

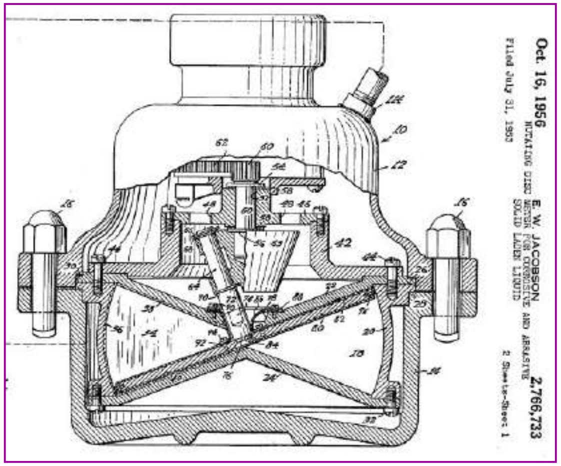
Innovative Mechanical Engineering

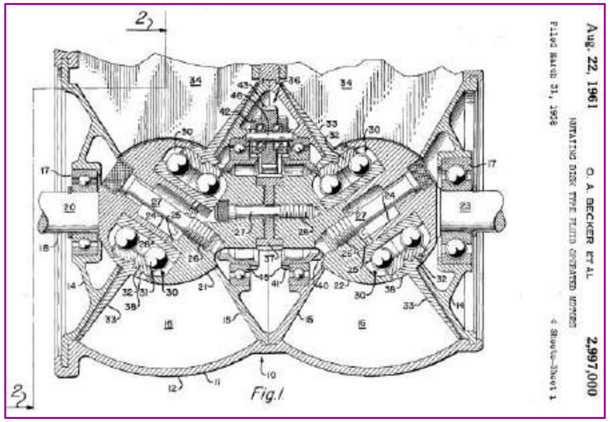
www.DesignSMART.co.nz

History of Wobble Plate Pumps





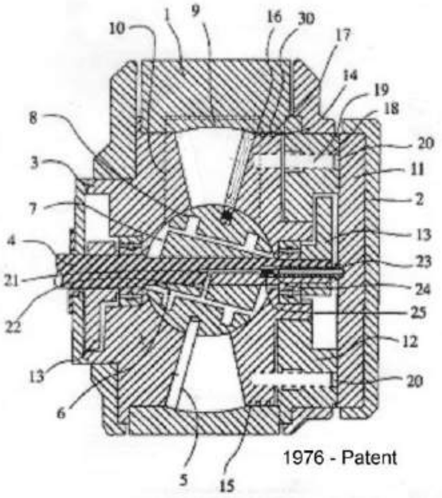




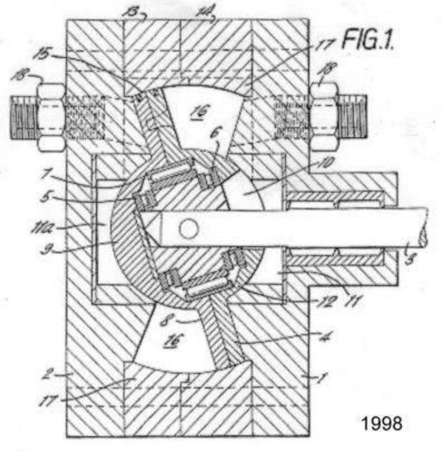
All these above designed without modern CAD/CAM & Simulation tools, however from what we know now this would have limited their progress, IP drawings shown above are from the 1950's & 1960's. They all utilizes the slant axis principle which has been around since 1896, (the oldest IP that we discovered).

Wobble Plate Pumps, the NZ History

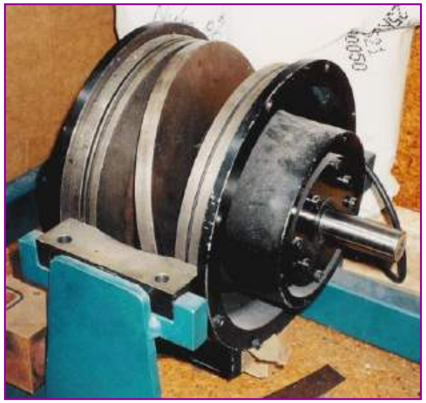
- Was firstly know in NZ as the Parker Pump, named after Alf Parker, an ex British World War II Royal Air force engineer who immigrated to NZ.
- This slant axis mechanism was adapted by Parker into a Vacuum Pump in New Zealand in the 1970's (without CAD CAM).
- He lodged his first Patent in 1976, his last in 1998 just prior to his death.
- Parker ran his pump(s) oil lubricated (as a sealing agent) rather than as a dry running vacuum pump.
- Vacuum Pumping Systems, partnered with him in 1995 & converted it into a non lubricated dry running Vacuum Pump & continued the development.
- SwashPump Technologies then took the IP & made significant inventive step to the IP between 2007 & 2017.



1976 - Patent



1998



Resources used during recent NZ development

- SolidWorks 2002 through to SolidWorks 2016.
- SolidWorks Simulation (FEA) in all of the above.
- SolidWorks PDMWE, 3 full users & 3 contributors, (2007 to 2012).
- SolidWorks Motion / Mechanism design, re dynamic balance.
  Also Industrial Research support in the early development.
- CFD support from Paul @ Matrix Applied Computing in 2008,
  using STAR-CCM+ from CD-adapco.
- NC manufacturing & tool making by RPM and Axiam Engineering.
- Injection (over) moulding by Galantai & Absolute Plastics.
- CMM QA support from Brendan @ Axiam Engineering,
  who are also SolidWorks users.

Wobble Plate Pumps (NZ) History continued

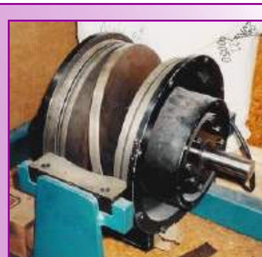
1

Oil sealed

Parker Pump

1970's

2



Dry

Vibration

Vacuum Pumping Systems

1990's

3

Ni-Resist Iron Pump

1500 Nl/min

Vacuum @ 500 mbar

Greater Efficiency
With Reed Valves

Lower Exhaust Temperatures

Lower Body Temperature

Lower Wear

Lower Vibration

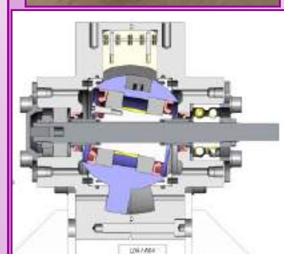
Lower Noise

2002 / 2006

Vacuum Pumping Systems

Target, Milking Systems

4



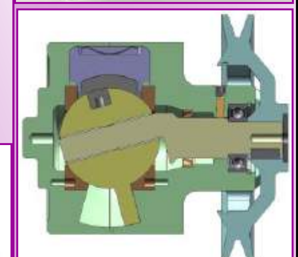
Slant Sleeve config

Vacuum / Blower

Liquid & Gas

2007

5



Petrochemical

No Valves

Energy Efficient

2008 - 2017

SwashPump Technologies

Target, Petrochemical

6

Twin Plate
Vacuum, Blower

Direct Drive Liquid

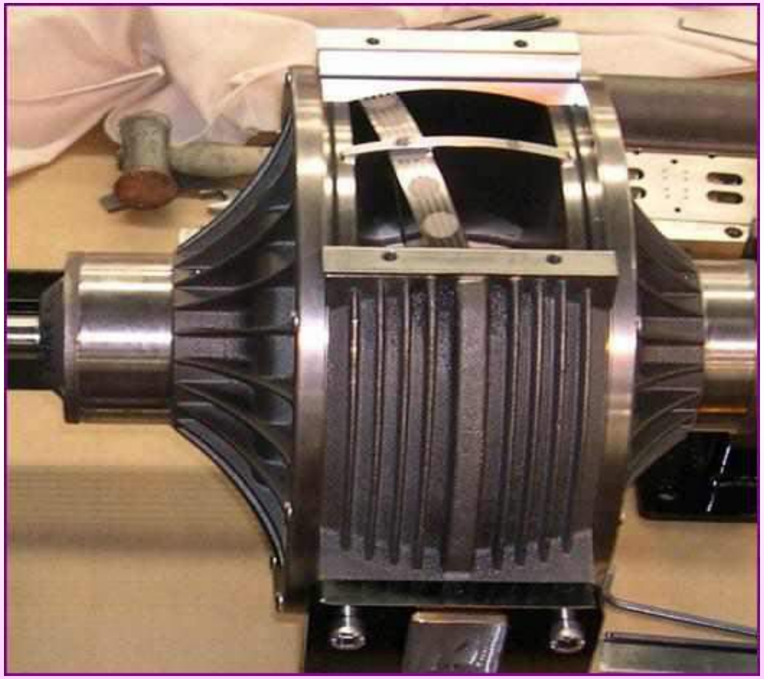
Direct Drive
Pressure control

Plastic Pumps

Possible Future ?

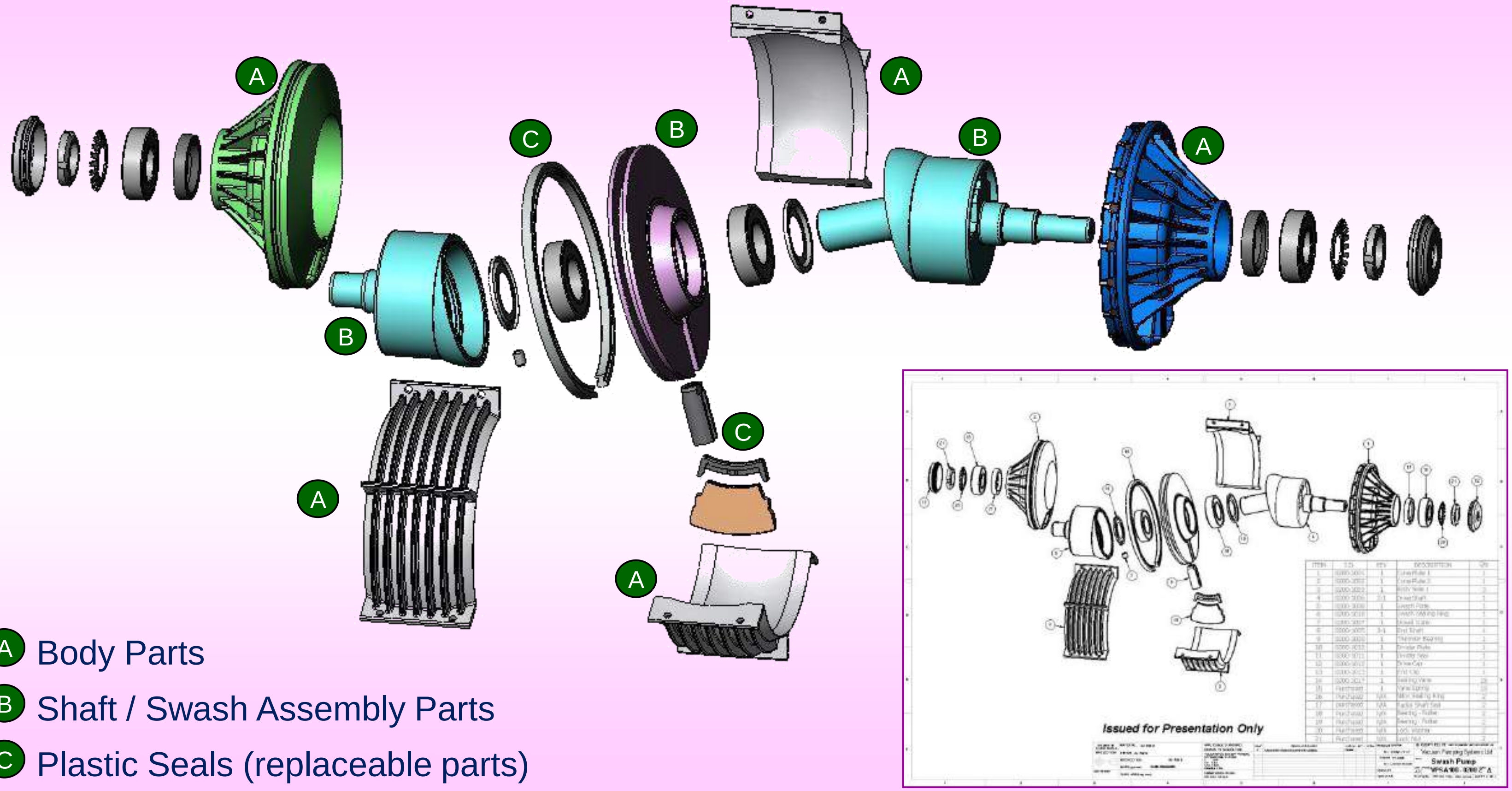
Vacuum Pumping Systems, Version 03 Pump

500 mbar 1500 Nl/min Vacuum Pump
Target market was milking systems (2004)



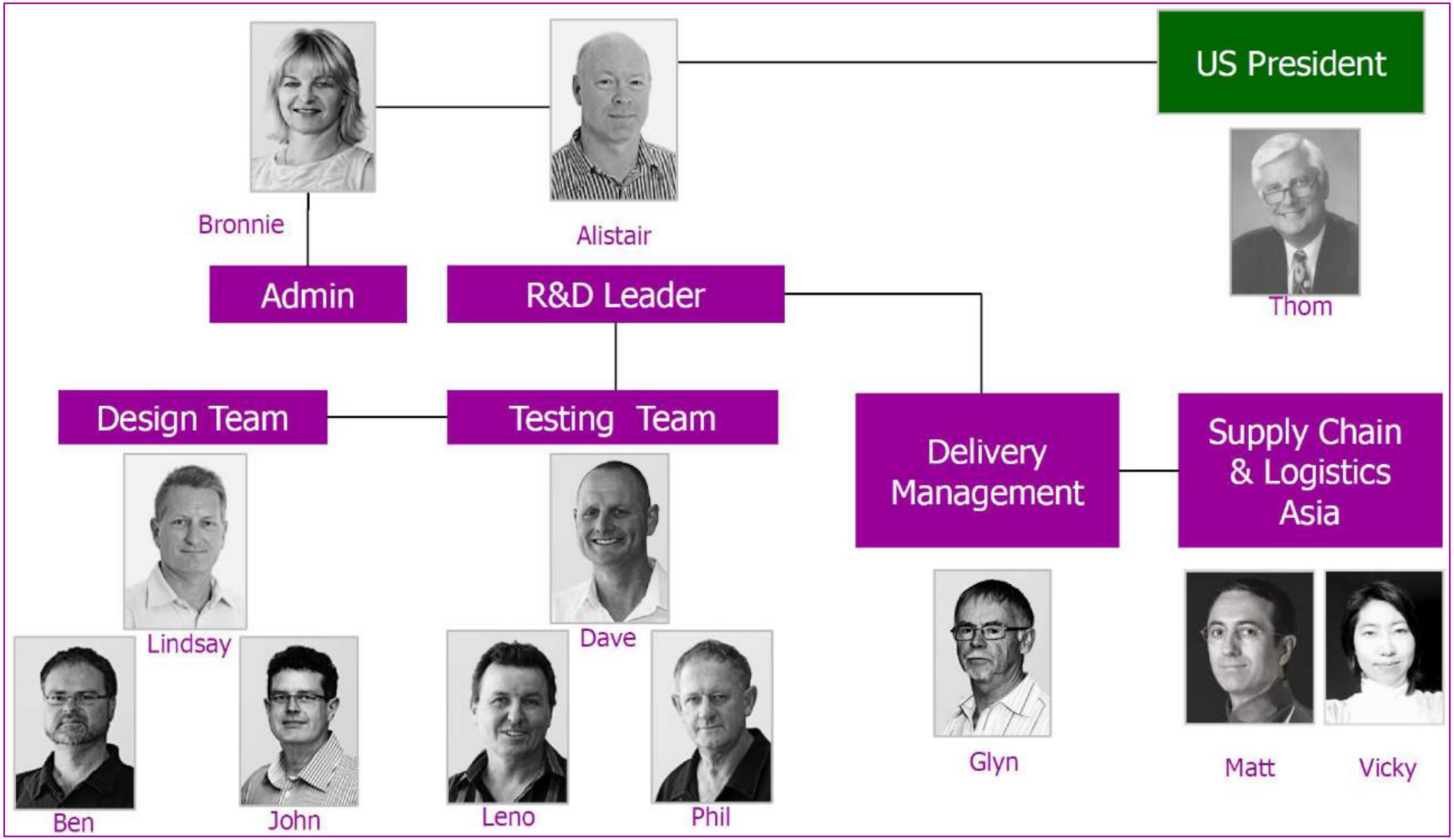
The Version 03 (Vacuum) Pump Design

Typical Version 03 Pump, Exploded Assembly View

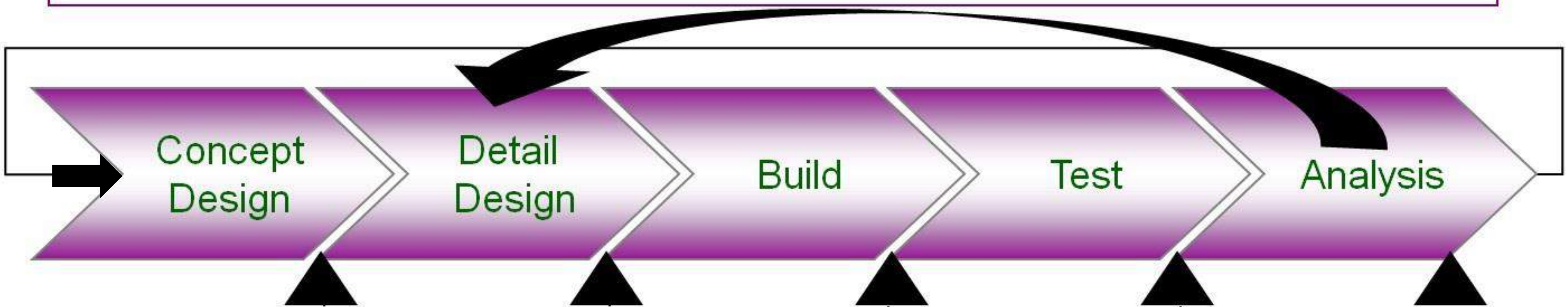


- A Body Parts
- B Shaft / Swash Assembly Parts
- C Plastic Seals (replaceable parts)

The SwashPump Team (2009)



Typical Development Process



Concept Design

- Design Document
  - Objectives
  - Scope
- Concept Model
  - Whiteboard
    - Geometry
    - materials
  - Calculations Analysis
  - CAD, Basic geometry
- Test Plan

Detail Design

- CAD Models
- CAD Assembly
- Materials Spec & Codes
- Tolerance Stack
- Final drawings & ParaSolid
- QA Drawings & ParaSolid
- Initial Quotes

Build

- Final quote
- Manufacture
- Assembly
- Acceptance

Test

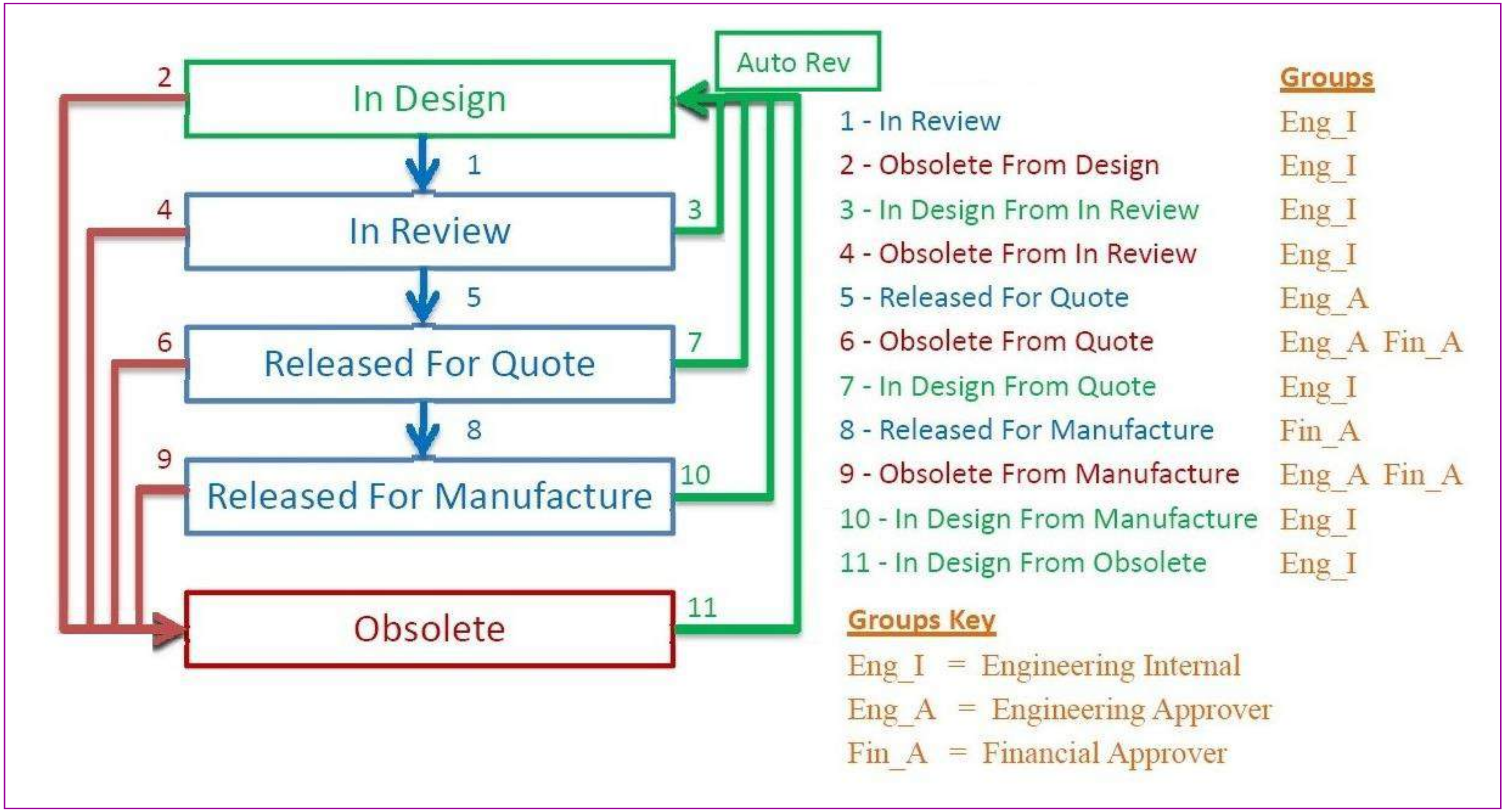
- Test Setup
- Testing, based on agreed Variables
- Possible agreed minor product change
- Possible agreed Test Iterations

Analysis

- Initial Testing Report
- Initial Analysis
- Iterative Testing Report
- Iterative Analysis

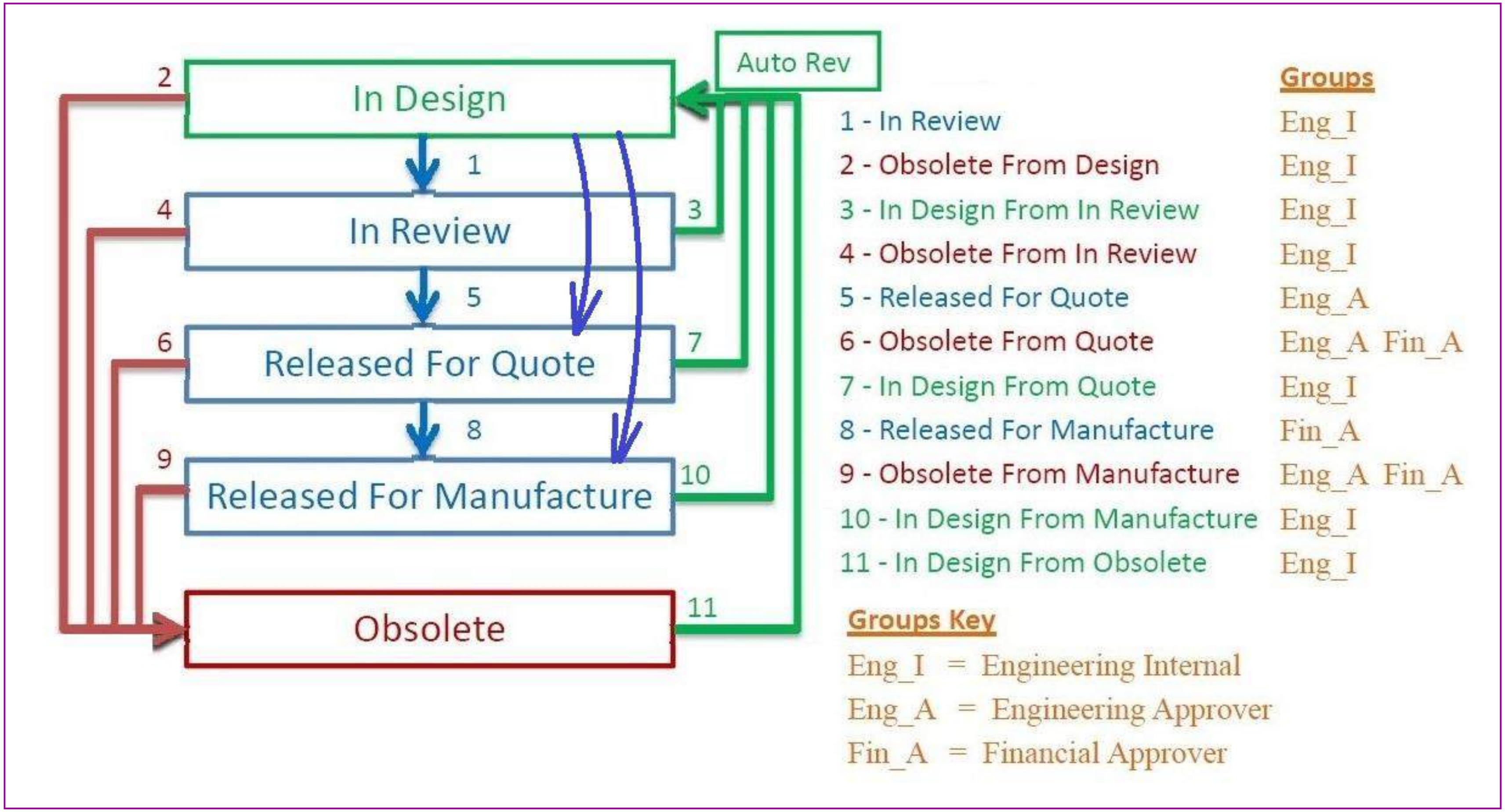
▲ Go / No Go Milestone

The SwashPump PDMWE workflow



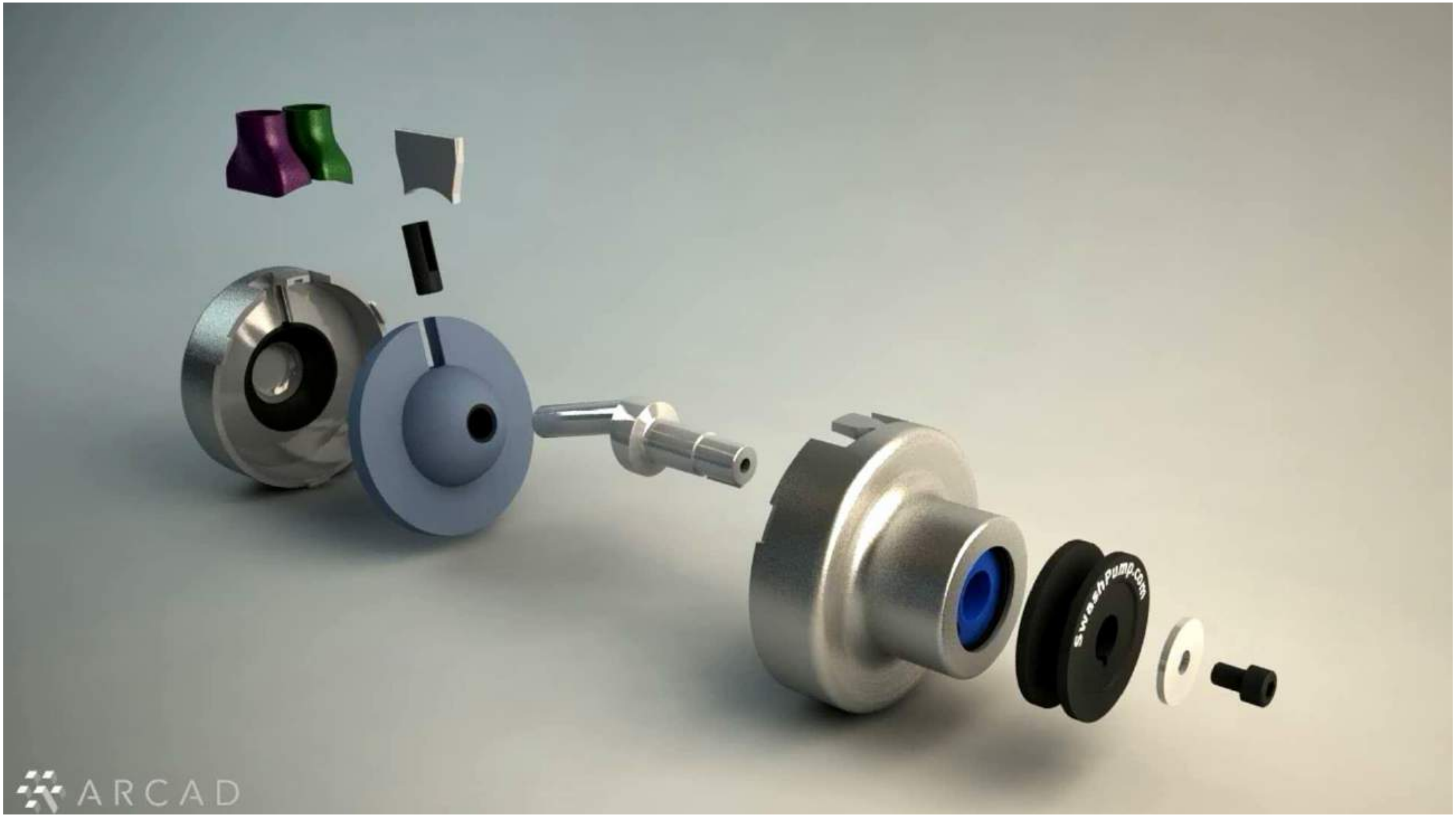
Note revision control of part configurations was done via revision management of drawings (only) each drawing created from specific part configurations.

Improved SwashPump PDMWE workflow



Note revision control of part configurations was done via revision management of drawings (only) each drawing created from specific part configurations.

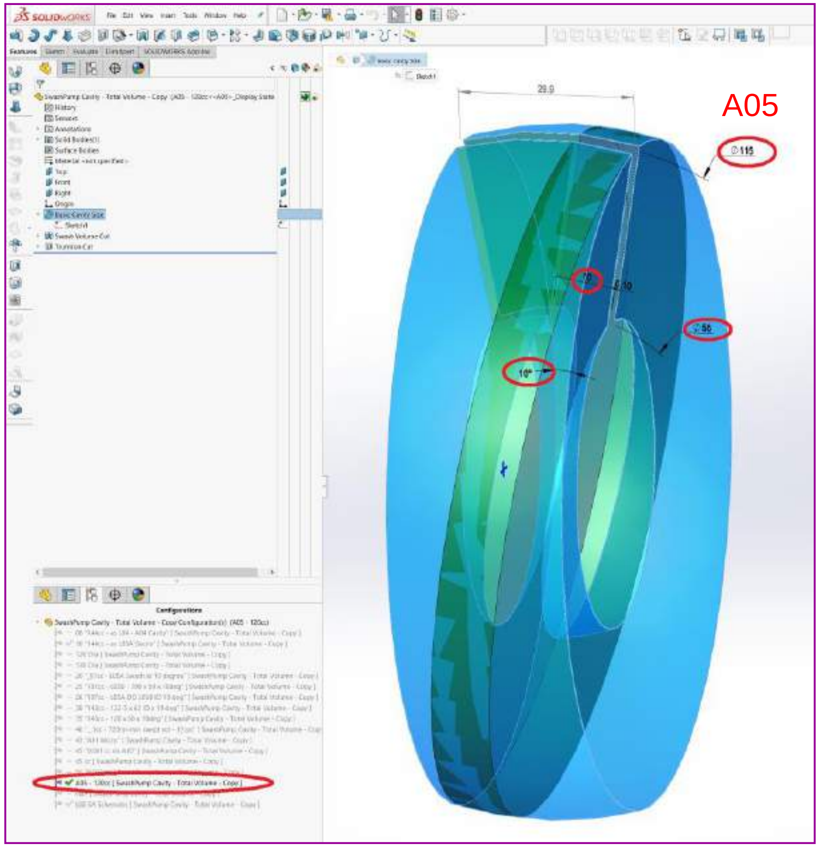
SwashPump Version 05 Liquid Pump Assembly



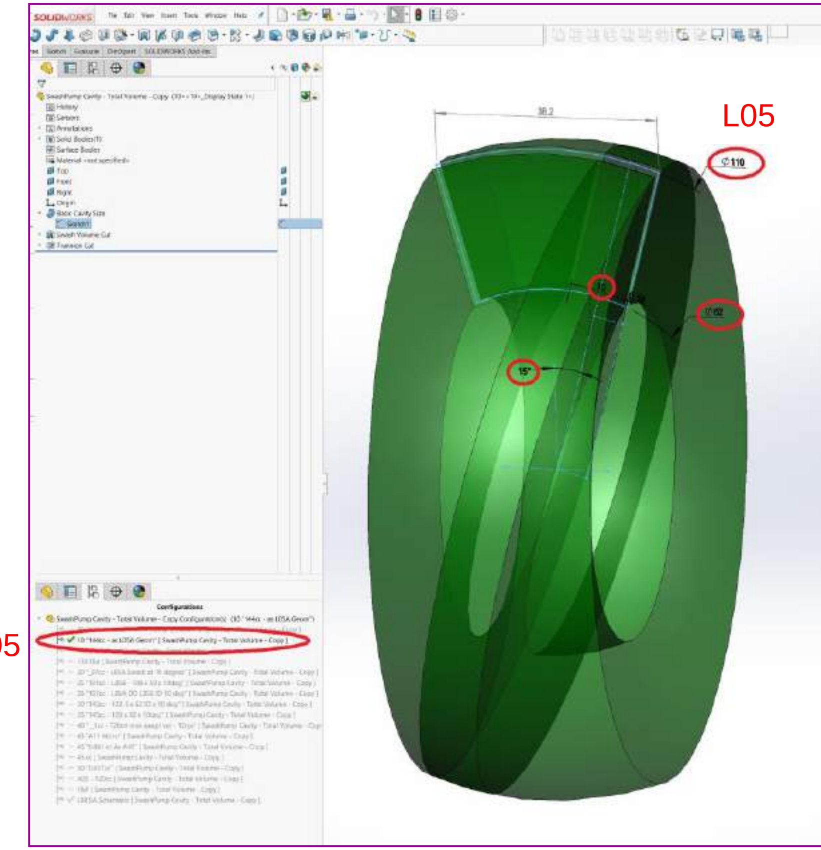
SwashPump Version 05 Liquid Pump Motion

The Swept Volume / Important Dimensions

A05



L05

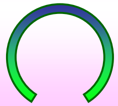


1) Outer Swash Diameter
2) Inner Swash Diameter (Hub Diameter)
3) The Cone Angle (Angle of Nutation)
4) Swash Thickness (subtracted volume)

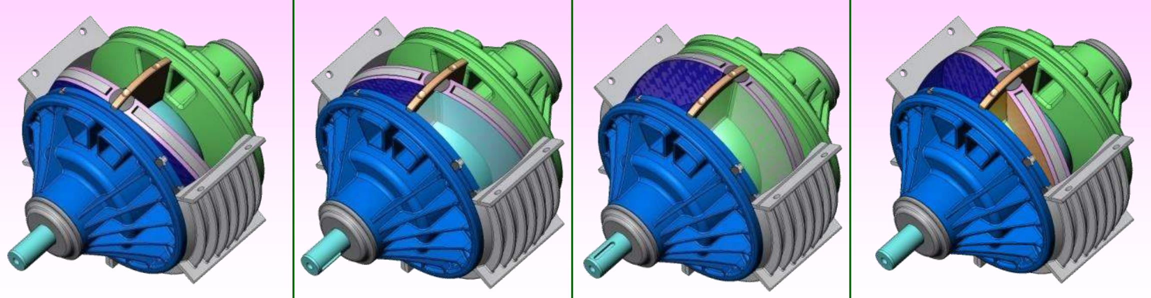
Nutating Plate Pump (non rotational)

Vacuum Application Swash v Roots

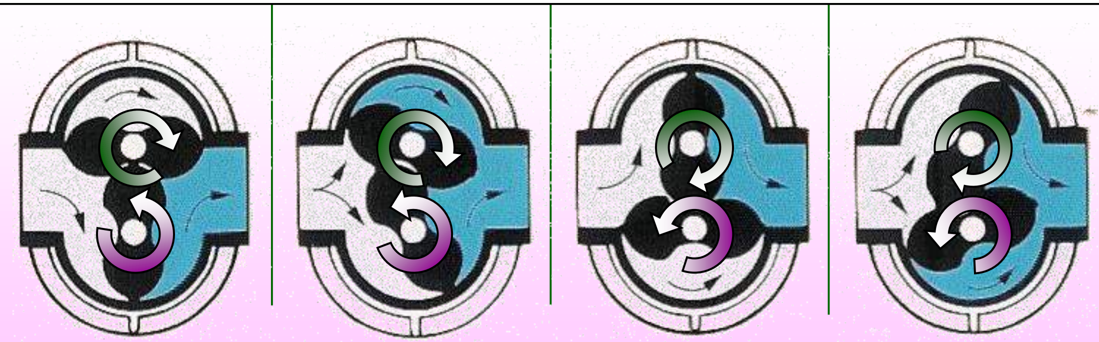
Valves & Mechanical Seals



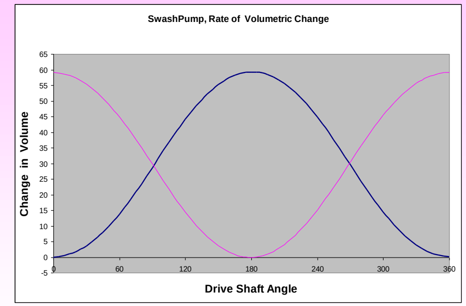
Valves (Reeds) can be fitted at the exhaust ports



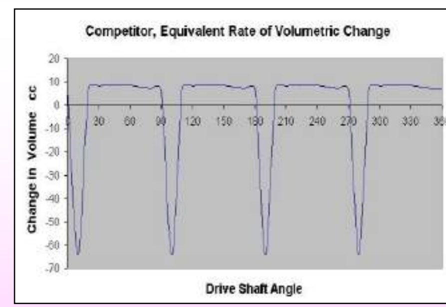
Cant Valve Roots Blower, suffers reflux positions 2 & 4



SwashPump Flow



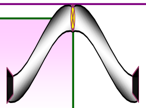
Roots Pump Flow



1500 Nl/min	Swash Pump	Current Technology
Volume	V	V

2

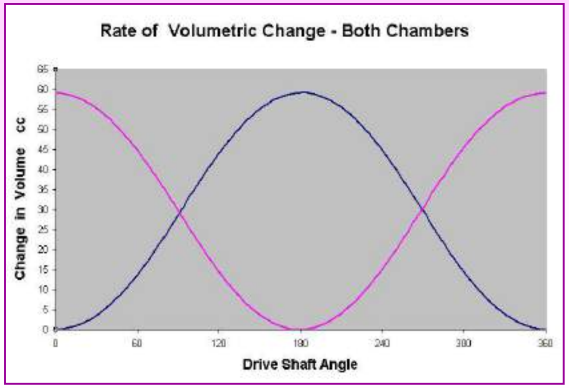
Shock Free Compression (sinusoidal)

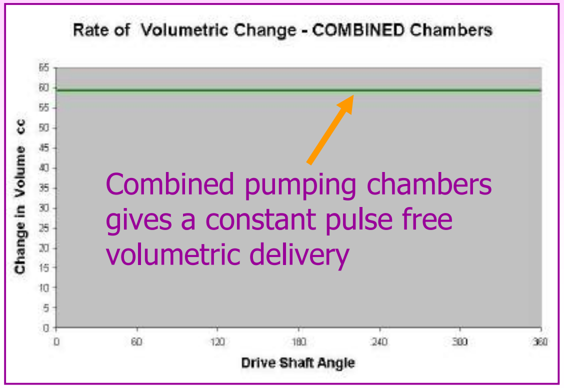


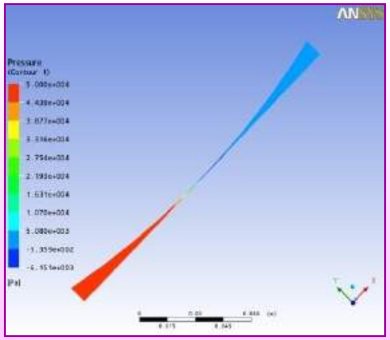
Flow & Leakage

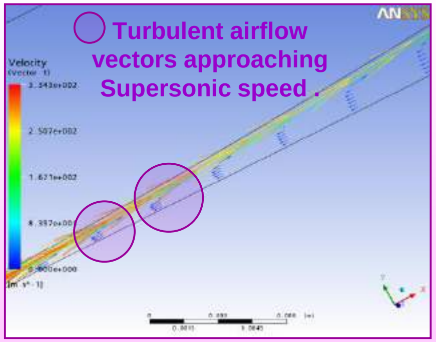
Low Leakage
Low Thermals

The Smooth Shock free sinusoidal compression from both Swash pumping chambers combine as shown









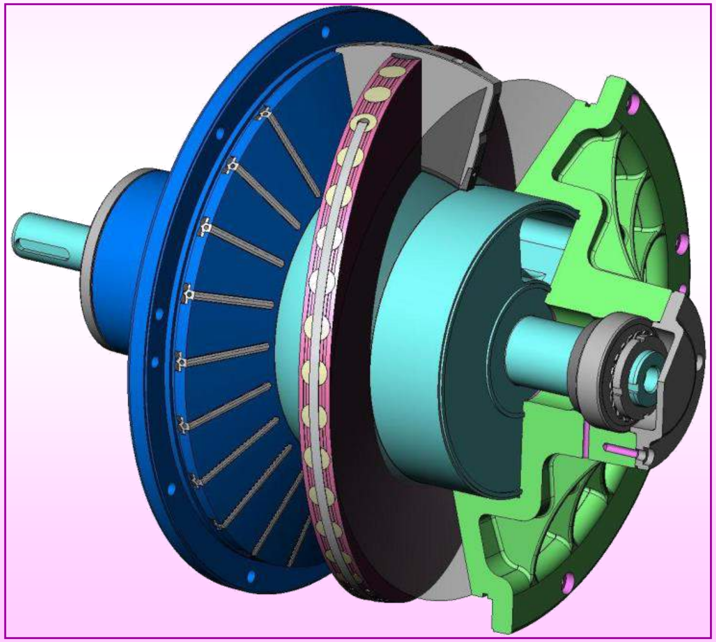
- The combined smooth shock free compression of the SwashPump gives a constant flow beyond the valves
- CFD modelling of the Swash to Cone air leakage velocity shown, lower right hand image.

1500 Nl/min	Swash Pump	Roots Pump
Volume	V	V
Thermals	T	1.4 T

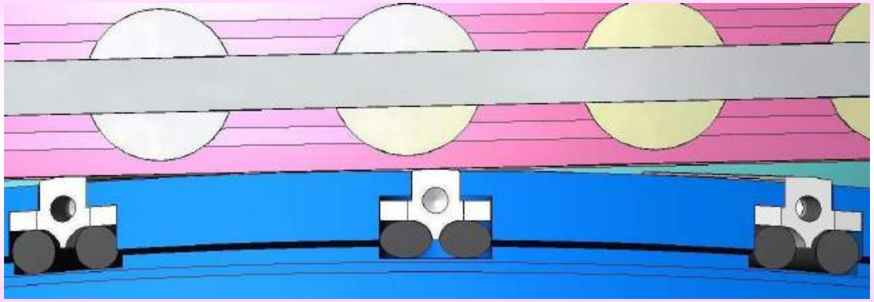
Mechanical Seals
Sealing Vanes

Mechanical Seals

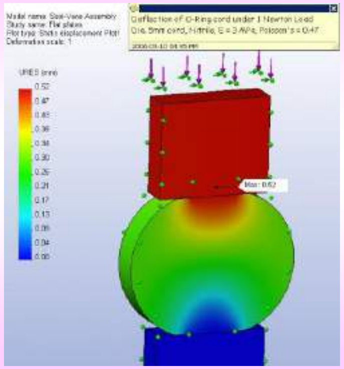
- The Sealing Vanes were introduced to ascertain what performance improvement would be achieved.
- Cost / benefit was marginal.

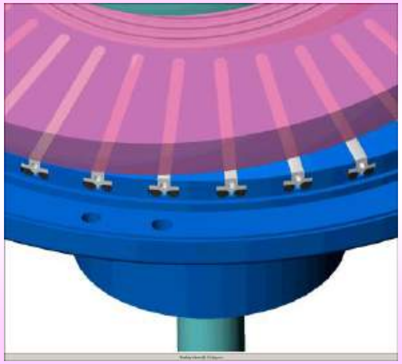


Sealing Vane End View



For AVI Video, Double Click Bottom right Image





The Swash Sealing Ring

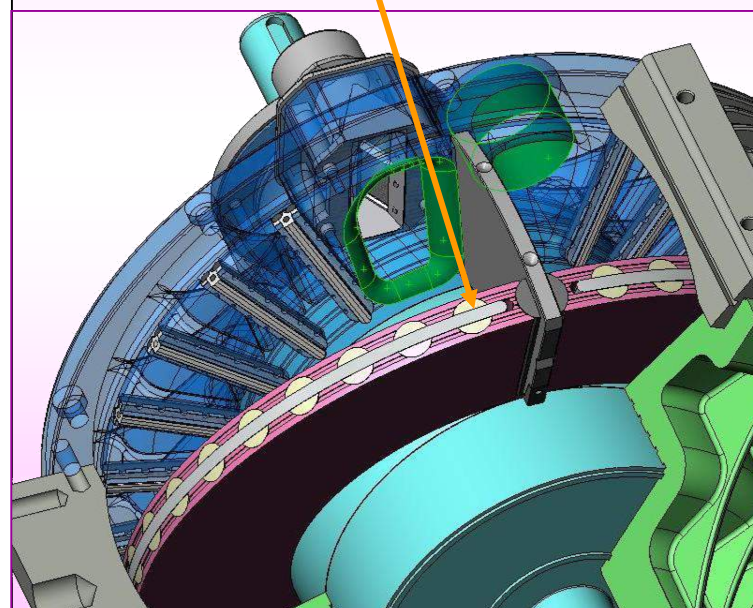
An Important Mechanical Seal for pumping air / gas

Mechanical Seals

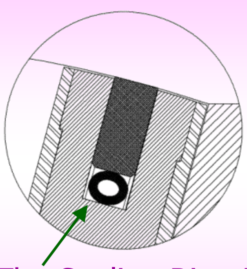
Sealing Ring

Version 03 Pump Design

The Sealing Ring
has a 350° arc



X-Sec & video, double click picture



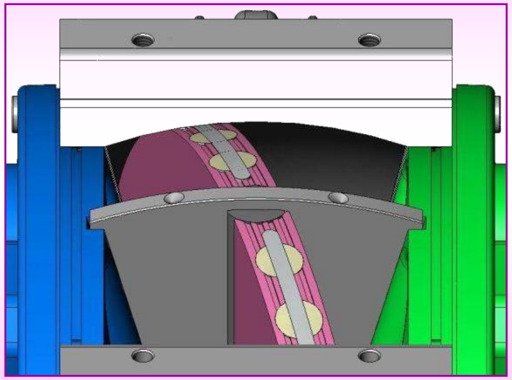
The Sealing Ring is
Energized with a
Rubber Backing Spring

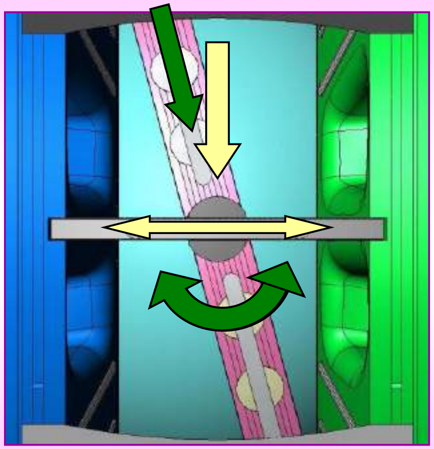
The Trunnion Bearing

Friction surfaces	Load type	Distance / cycle	Average Velocity
Trunnion to Divider	Perpendicular	180mm	Average 3.5m/sec
Swash to Trunnion	Radial	12mm	0.23m/sec

Trunnion Forces

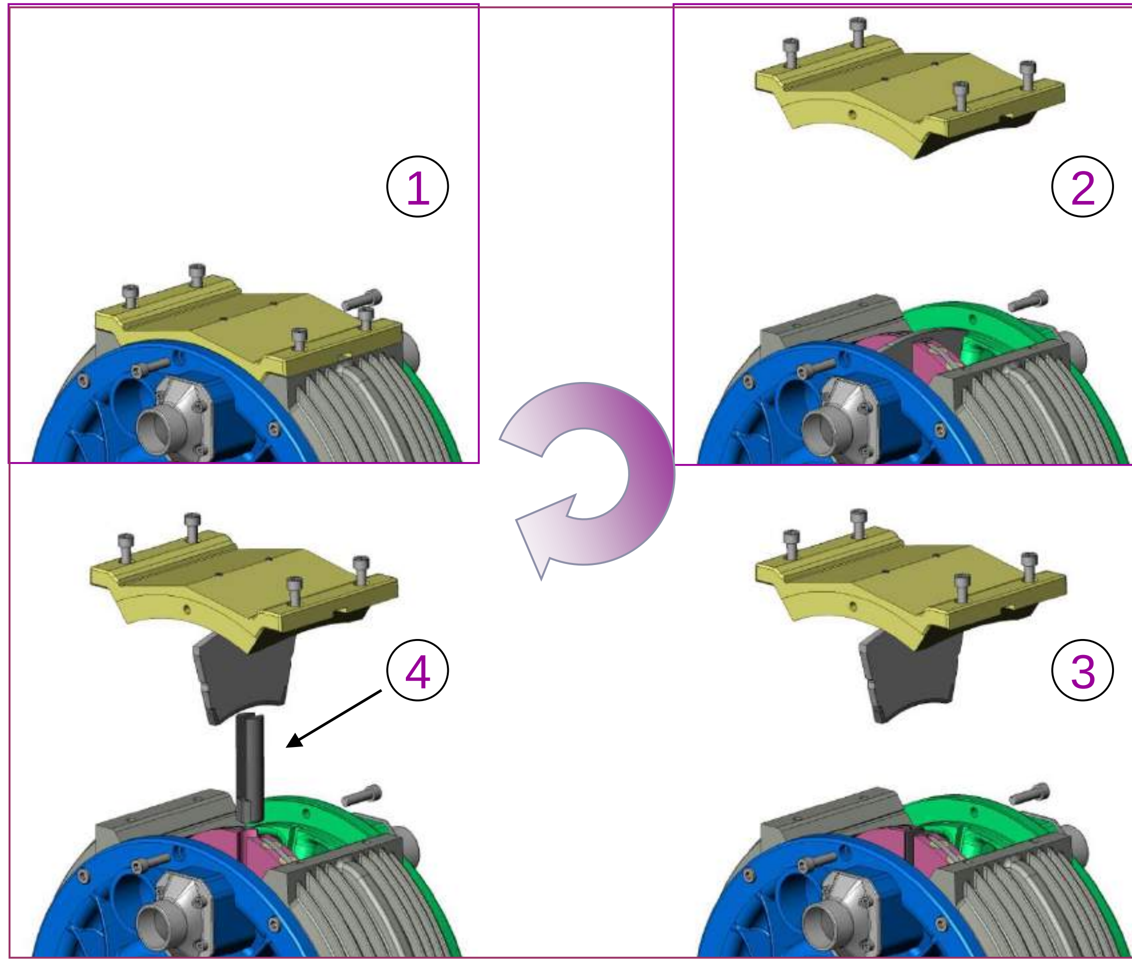
The Trunnion acts as both a Seal & Bearing as illustrated





Trunnion Serviceability

1. Loosen 6 Fasteners
2. Remove Divider Retainer (Body Top)
3. Remove Divider & its attached Seal
4. Remove Trunnion from Swash Plate
5. Replace Trunnion with new item if required, Reverse Steps 1 to 4.



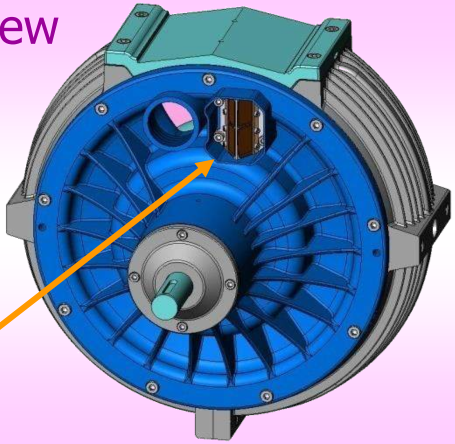
Exhaust Reed Valves

Required for higher than ***300mbar Vacuum*** applications

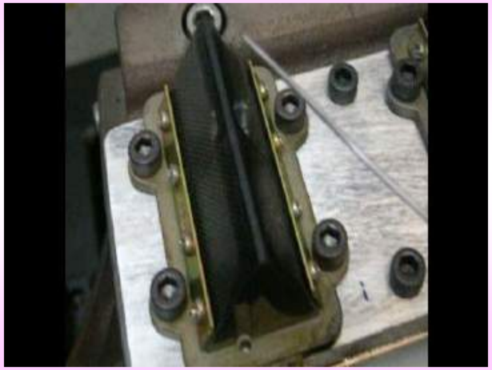
Mechanical Seals

➲ Carbon fibre Reed valves

03 Pump External View

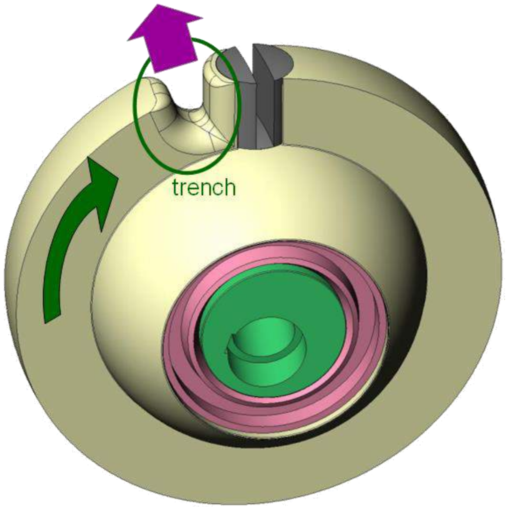


Reed valve in action

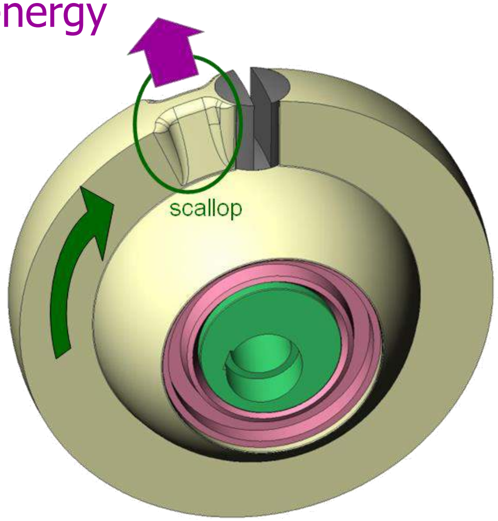


L04 Liquid Pump, Exhaust Analysis

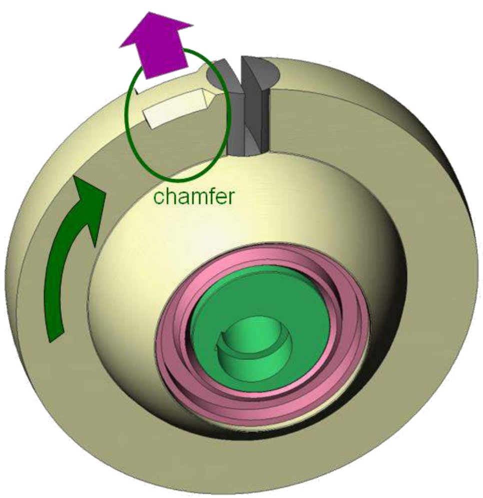
- Swash Plate Liquid Pump geometry options analyzed in exhaust region.
  - Reduced peak fluid velocity
  - Reduced fluid kinetic energy
  - Reduced max static pressures



Trench



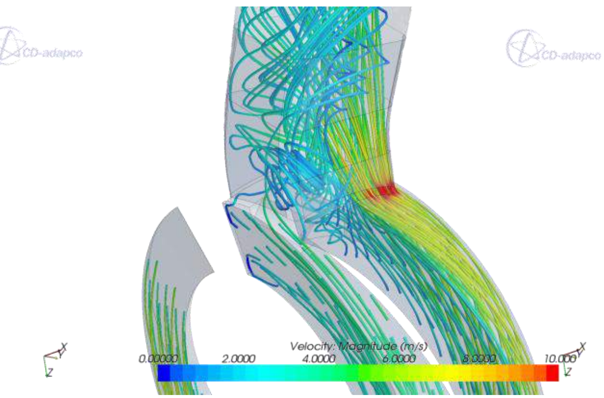
Scallop



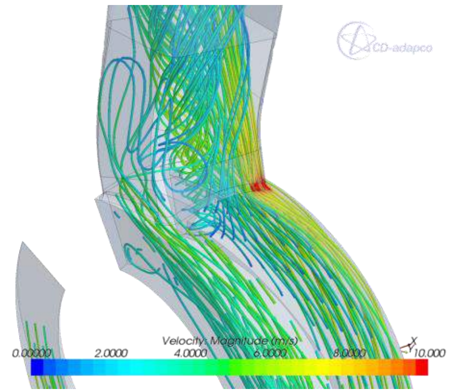
Chamfer

- Green arrow = direction of fluid during compression cycle
- Purple arrow = direction of fluid discharge through port

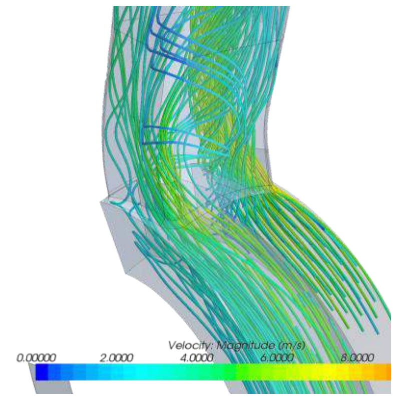
L04 Liquid Pump, CFD Exhaust Analysis



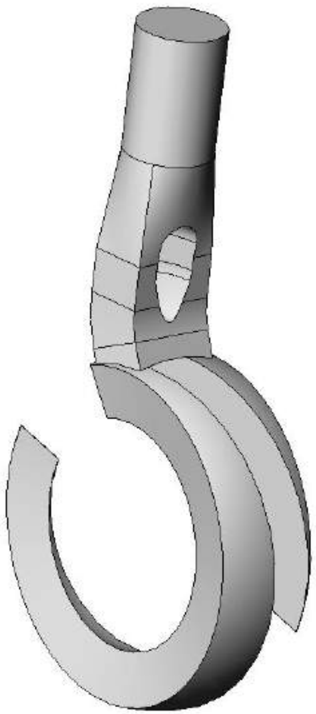
20 degrees

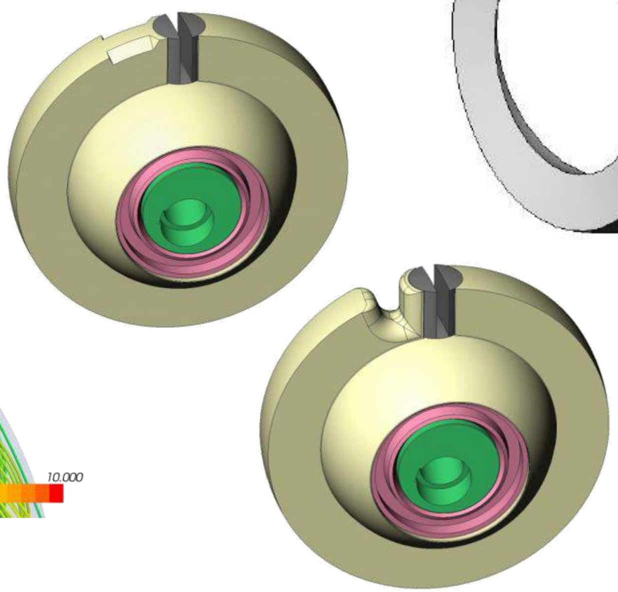


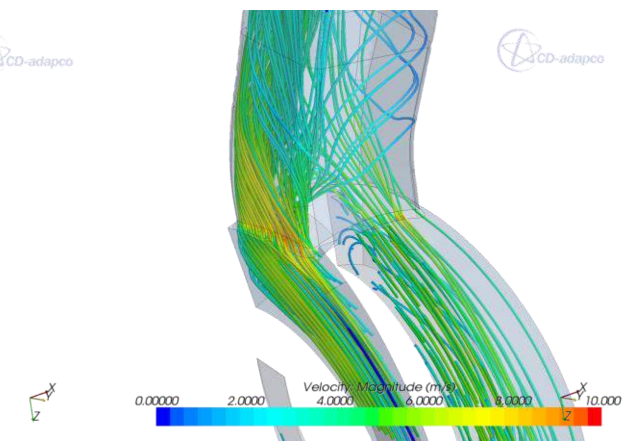
45 degrees



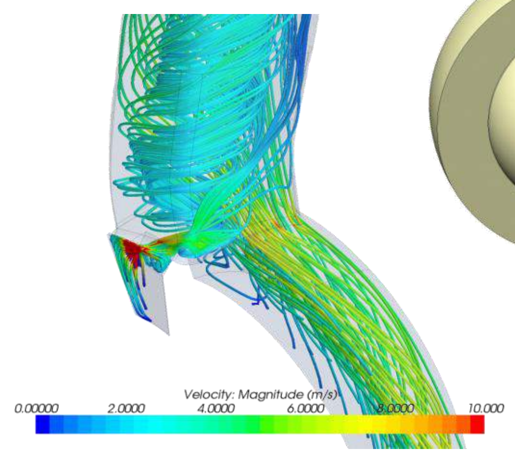
90 degrees





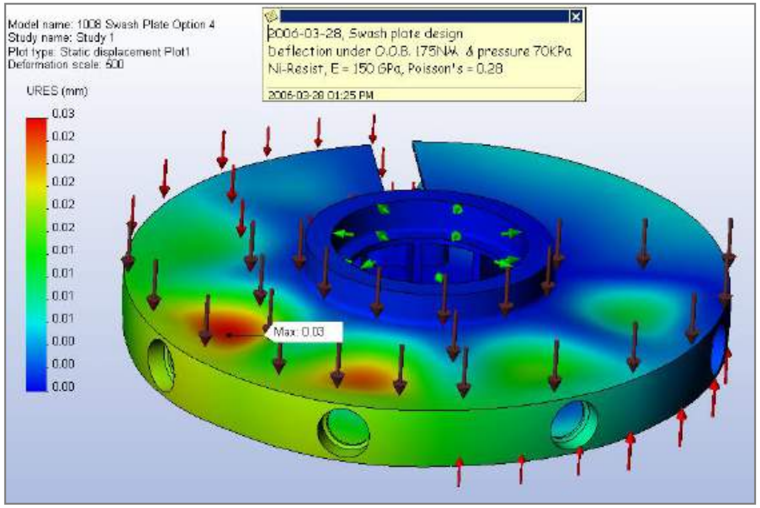


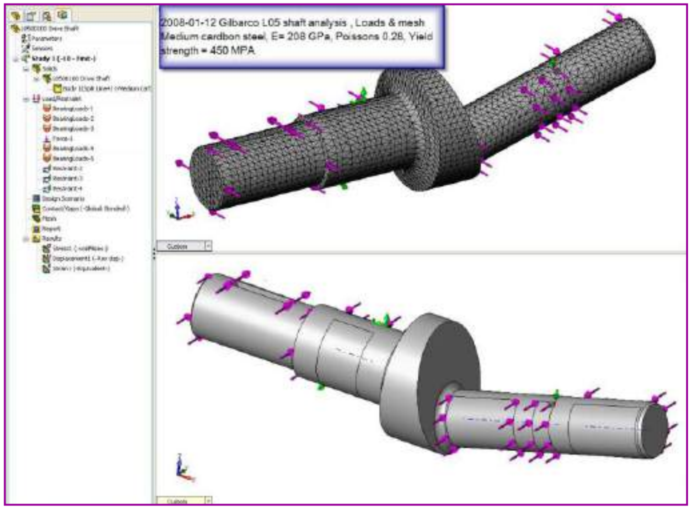
270 degrees



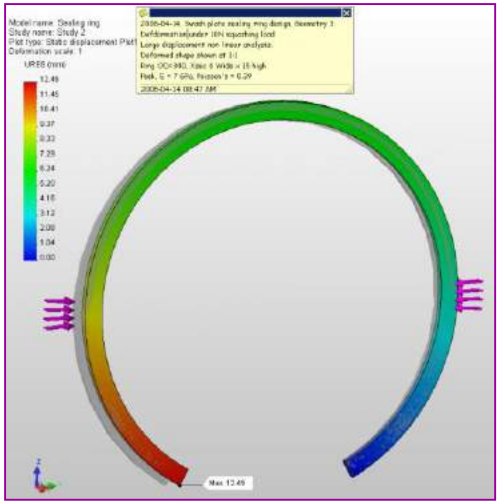
340 degrees

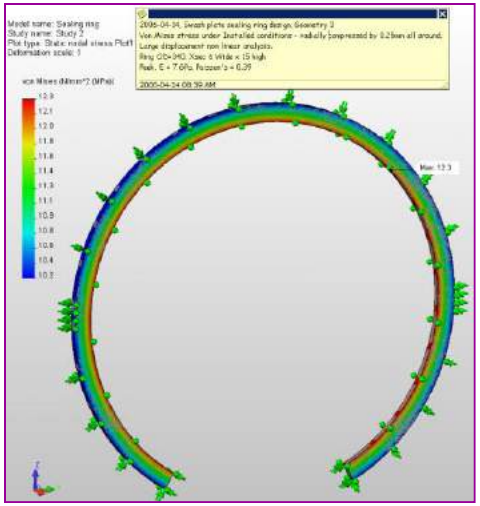
SolidWorks Simulation, where required

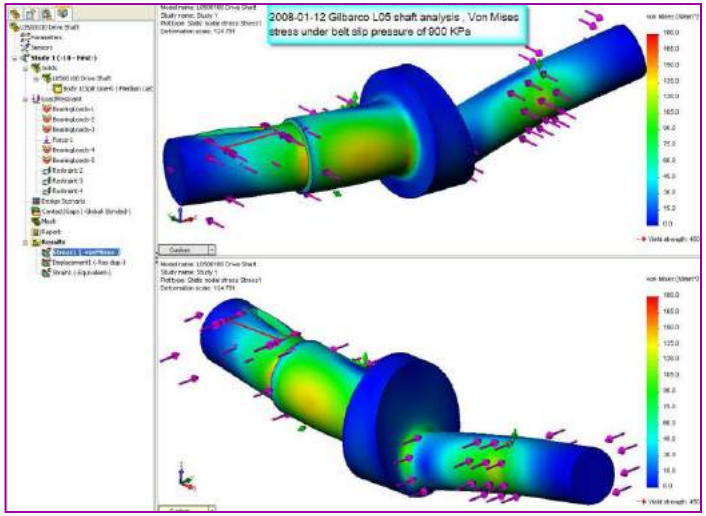




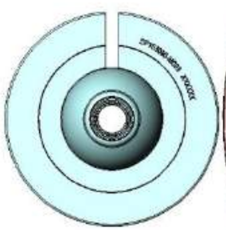
Simulation of Hollow Swash shown above



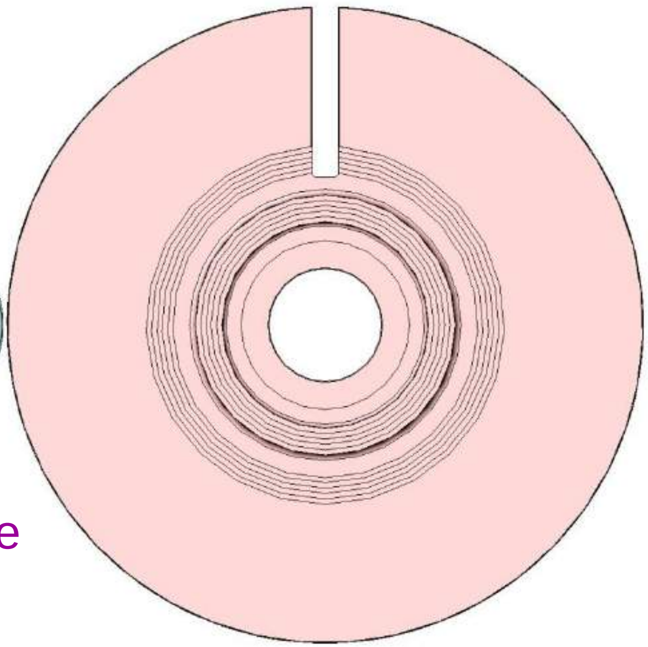




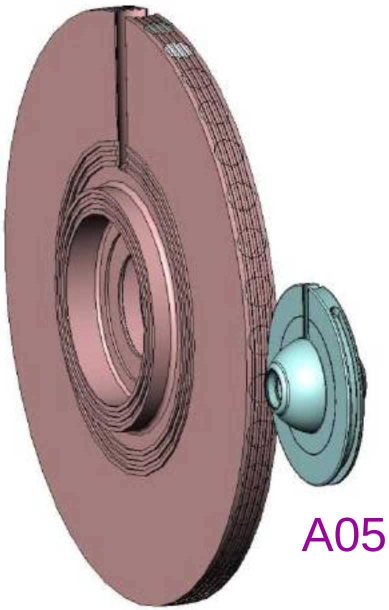
Dynamic balance of a Nutating (Wobble) Plate



A05-V4
Swash Plate



Series 03 Swash Plate

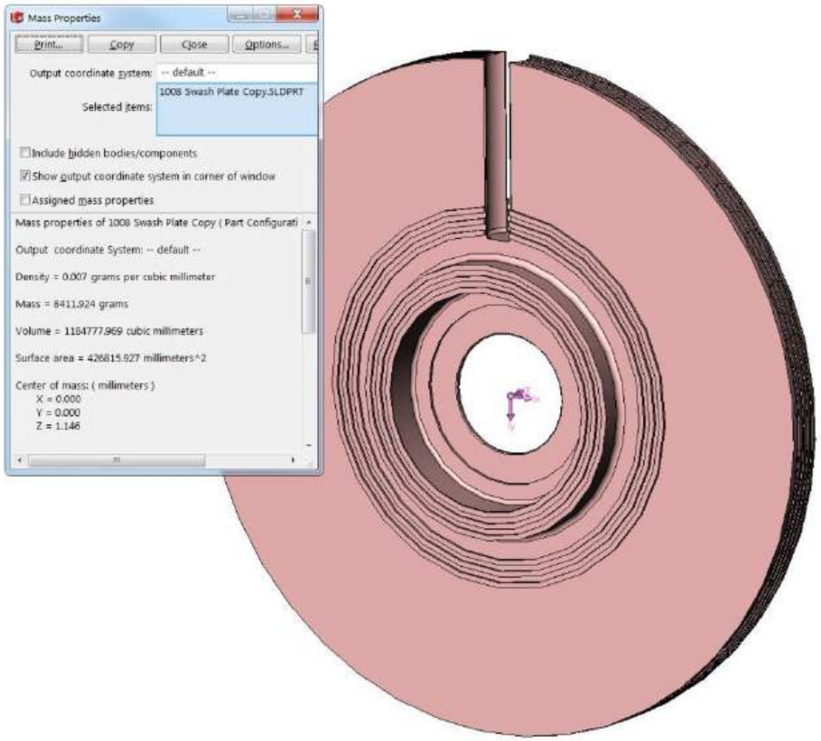


A05 = 10^o Slant

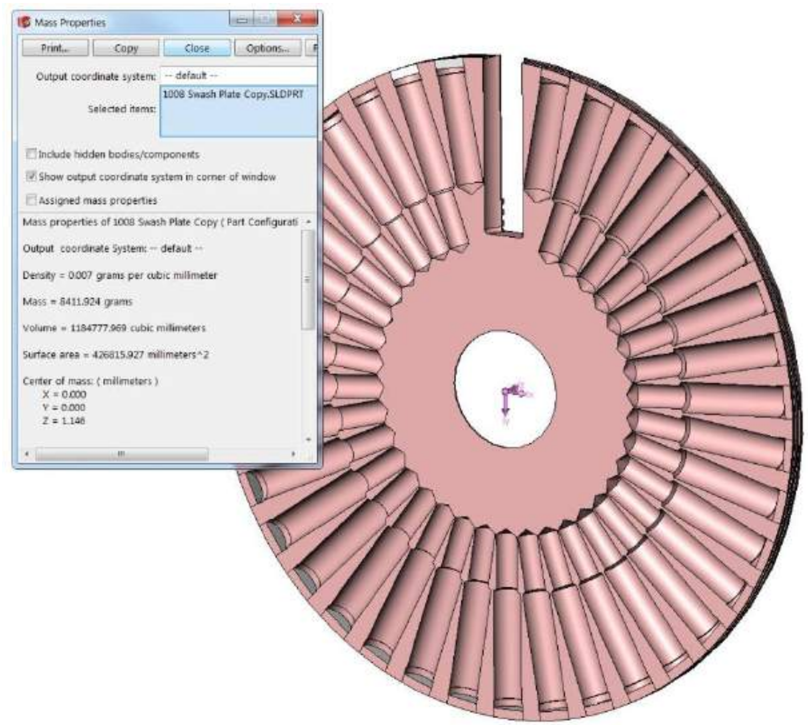
Series 03 = 15^o Slant

Size does matter! & Slant (travel) angle

Dynamic balance of a Nutating Plate



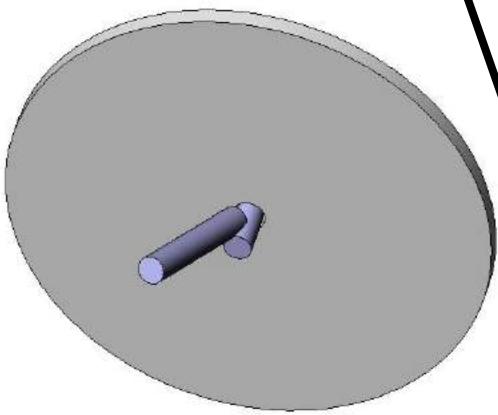
Series 03 Swash Plate

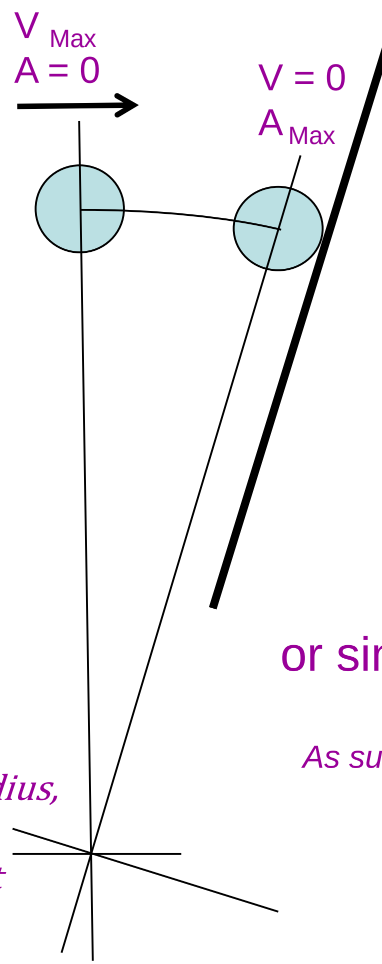


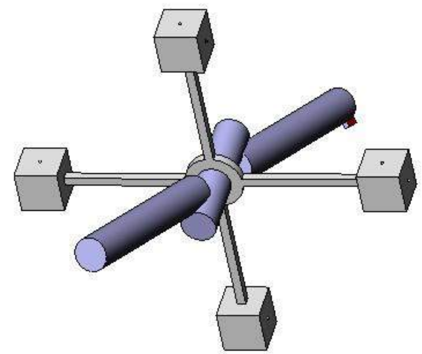
Weight / Mass Reduction

So obviously Mass / Weight matters!

Dynamic imbalance calculation methods







Simple Flat Disk Method

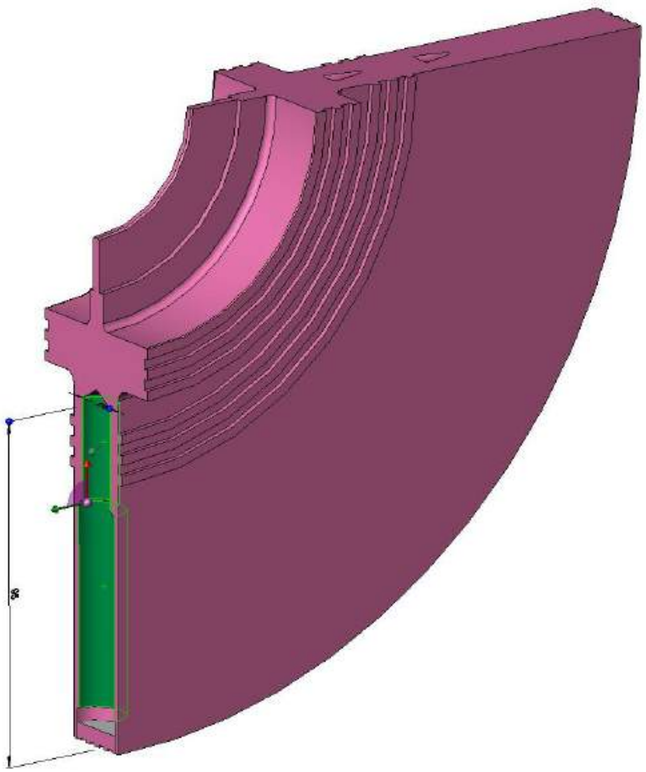
$$C = {}^{3.142}/_{4}\ p\,h\,w^{2}\ cosO\ sinO\ (r_0^{\,4} - r_i^{\,4})$$

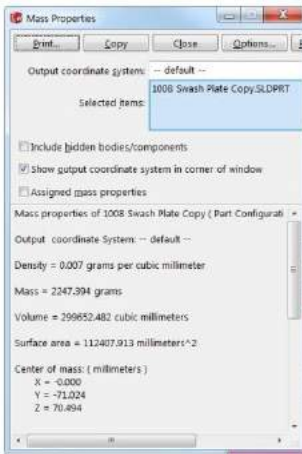
h = thickness, r_0 = Outer radius, r_i = Inner radius,
p = density, O = angle, w = speed (radians/s)
C = nutating imbalance in Nm delivered to Shaft

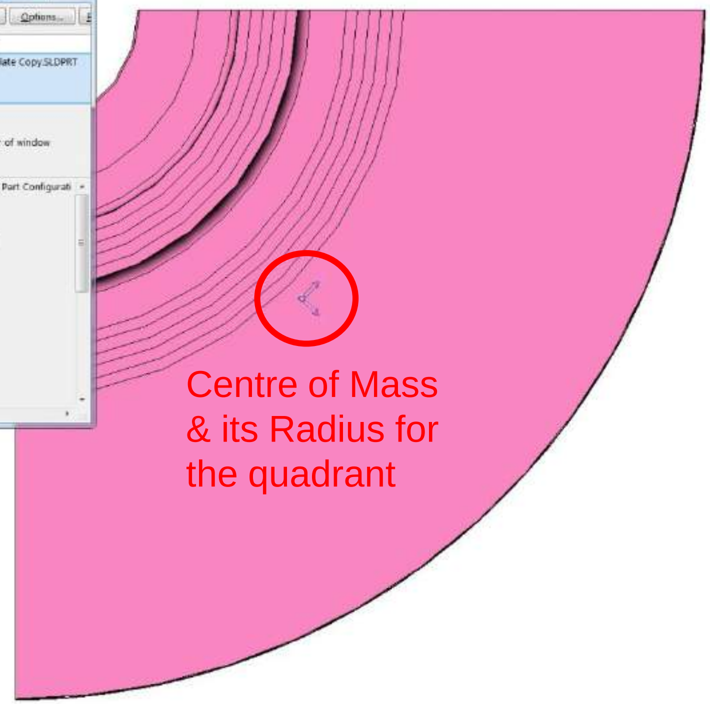
or simple 4 Lump Mass Method

A close approximation method ,
As suggested by Lan from IRL see next slides

Dynamic balance of Large 03 Plate







Dynamic balance of Large 03 Plate

- 4 Lump Mass (Close Approximation) Method

  ¼ Mass of Swash = 2.13 kg

  effective radius r = 0.10 m

  Distance d = r x sin 15^0 = 0.0259m

  Speed (1500rpm) w = 157 rad/s

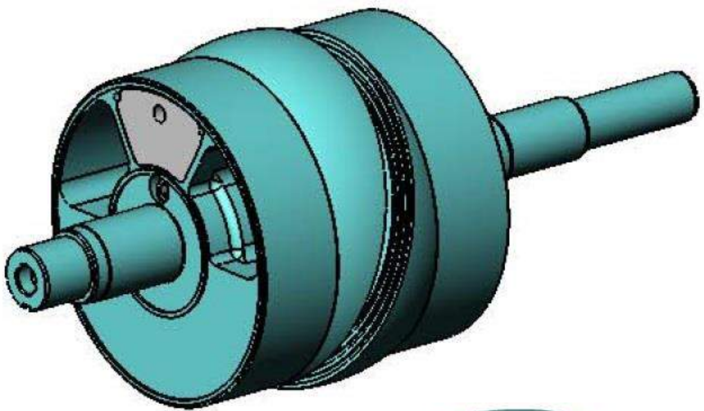
  Acceleration = d w^2 = 0.0259 x 157^2 = 638 m/s^2

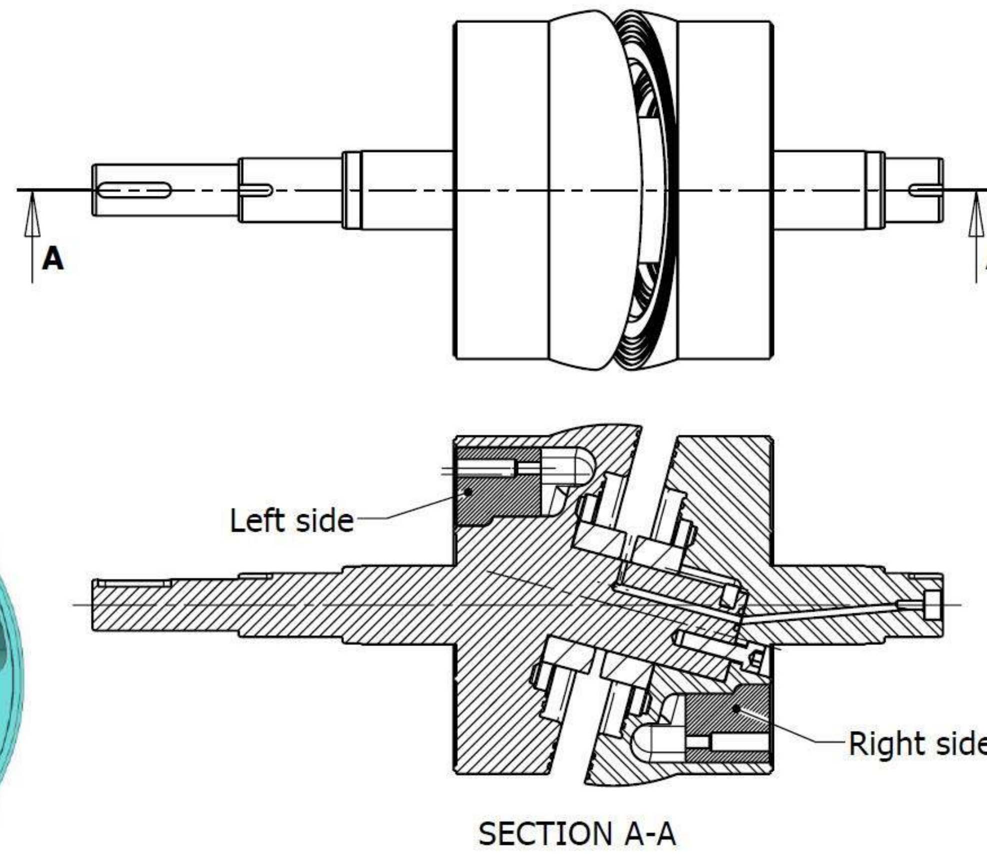
  F = m a = 2.13 x 638 = 1358.9 N

  Nutating Imbalance Couple = 2 r F = 2 x 0.1 x 1358.9 = **272Nm**

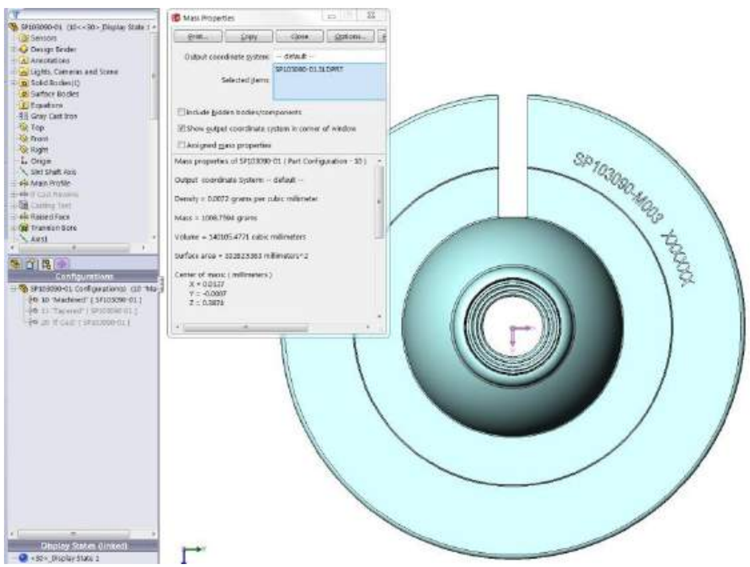
- **This was a significant imbalance for the total mass of 03 pump so we compensated for this within the pump.**

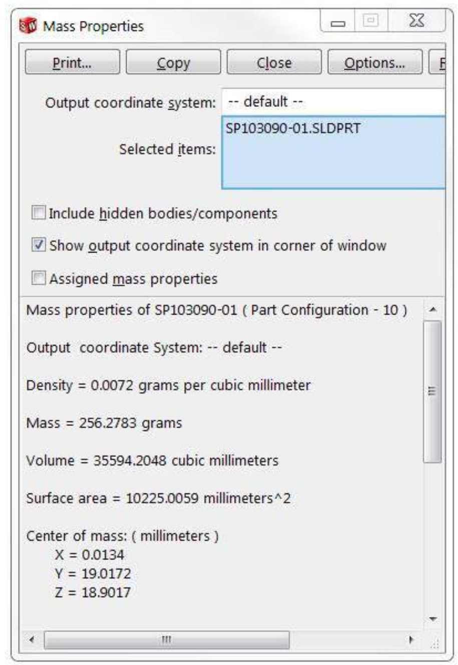
Dynamic balance rectification of large 03 Pump



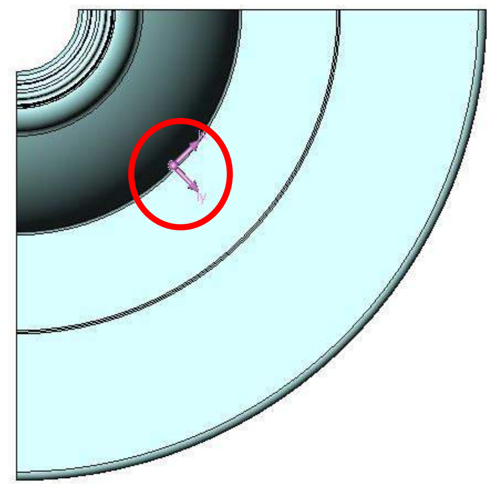


Dynamic balance of the small A05-V4 Plate





Centre of Mass & its Radius for the quadrant



Dynamic balance of A05-V4 Plate

- 4 Lump Mass (Close Approximation) Method

  ¼ Mass of Swash = 0.256 kg

  effective radius r = 0.027 m

  Distance d = r x sin 10^0 = 0.0047m

  Speed (1500rpm) w = 157 rad/s

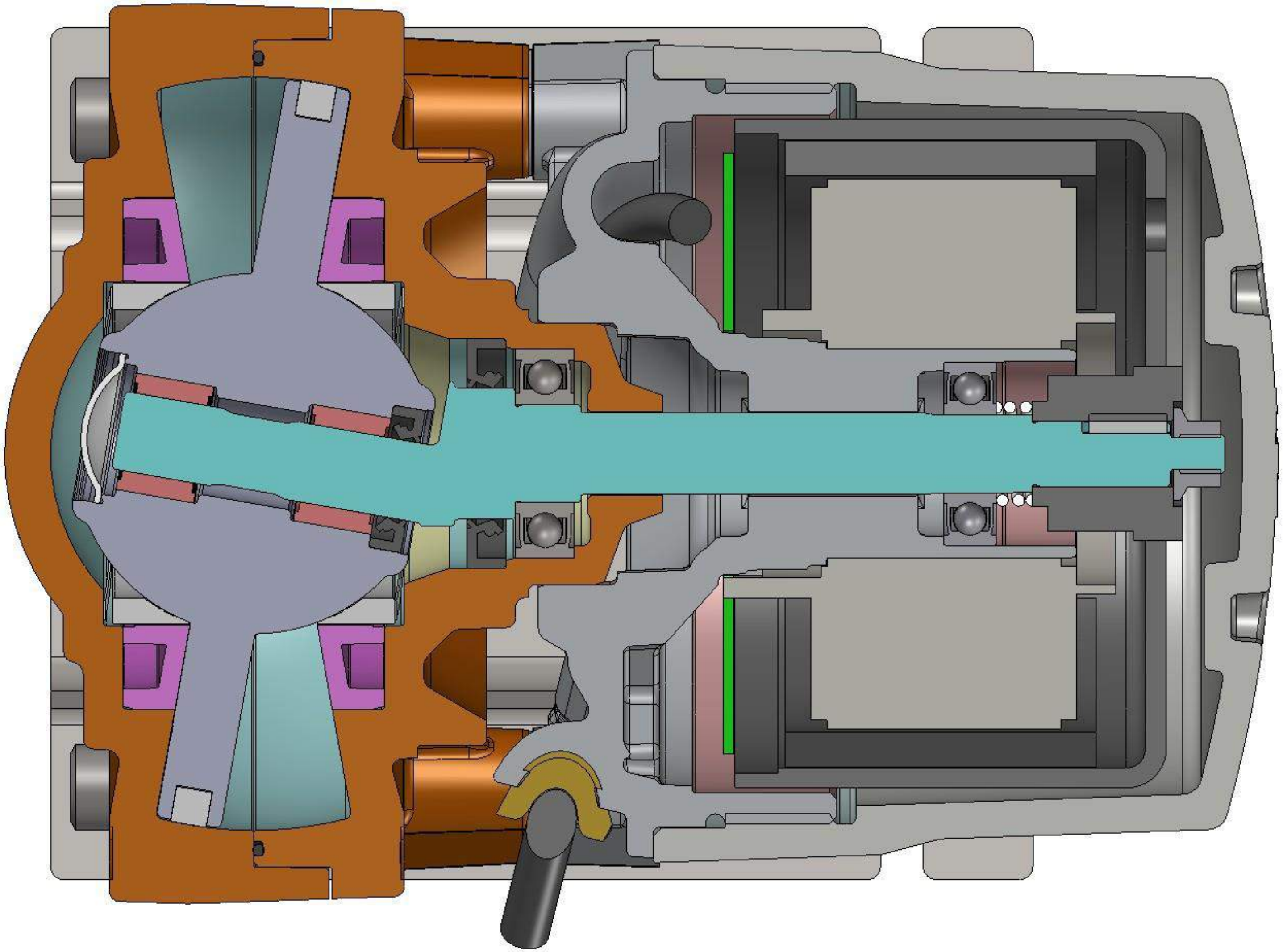
  Acceleration = d w^2 = 0.0047 x 157^2 = 116 m/s^2

  F = m a = 0.256 x 116 = 29.7 N

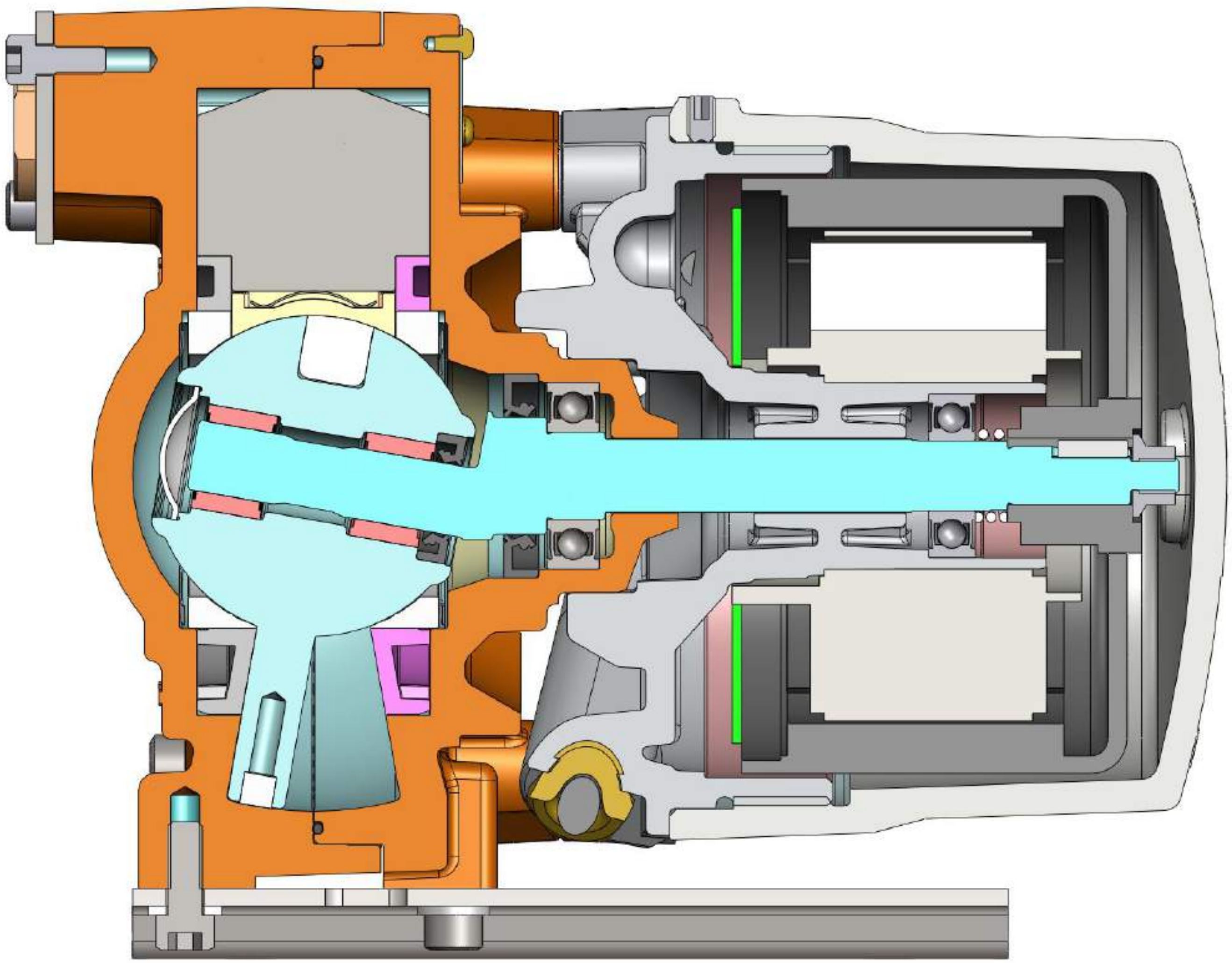
  Nutating Imbalance Couple = 2 r F = 2 x 0.027 x 29.7 = **1.6Nm**

- **This is not a significant imbalance for the total mass of A05 pump.**

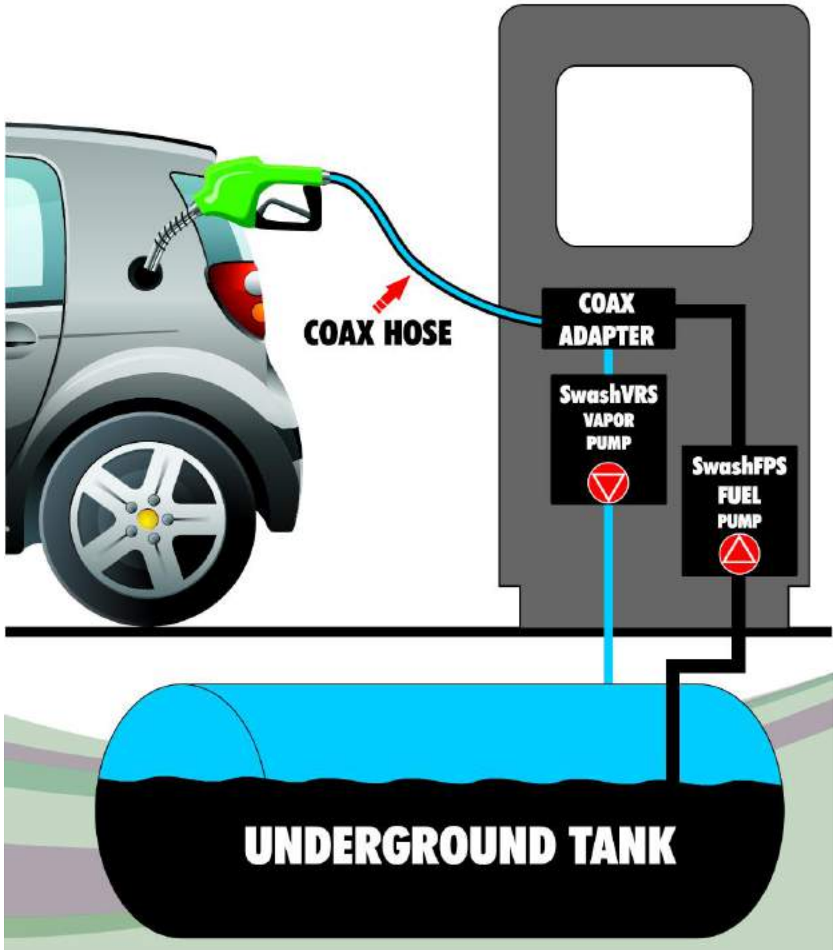
A05-V4 SwashPump Horizontal X-Section



A05-V4 SwashPump Vertical X-Section

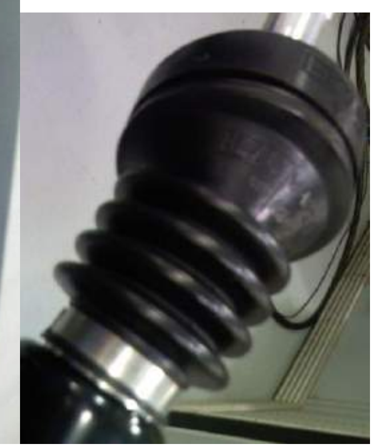


A05-V4 SwashPump Petrol Vapour Recovery

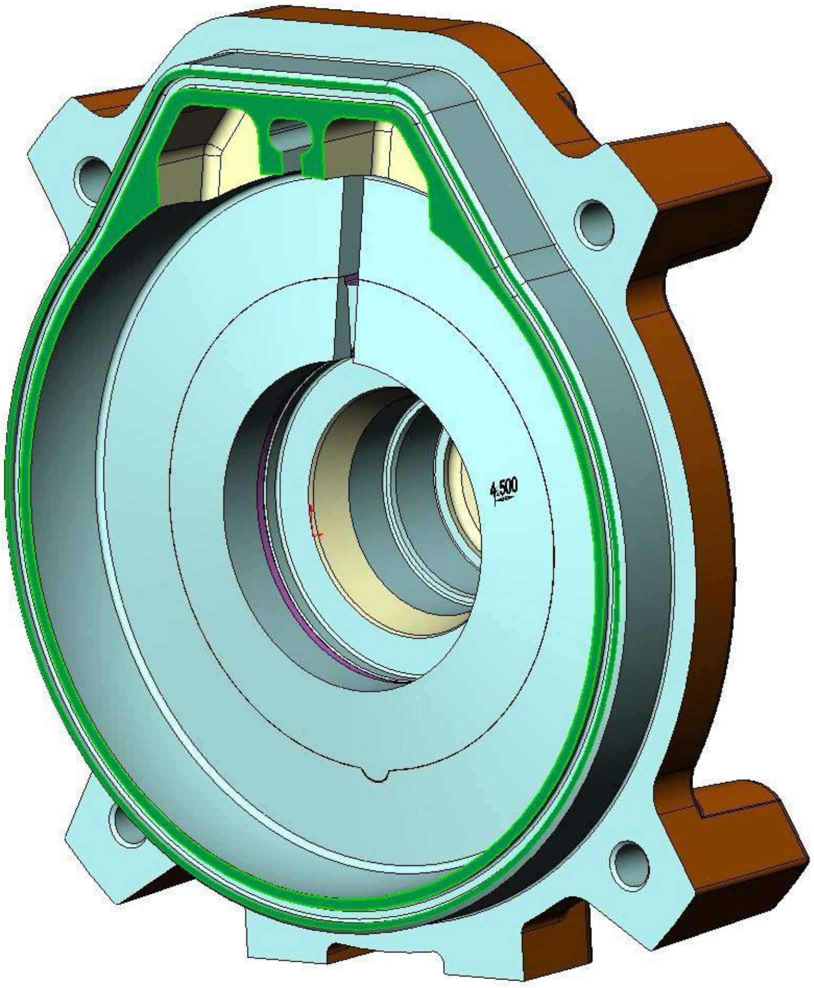


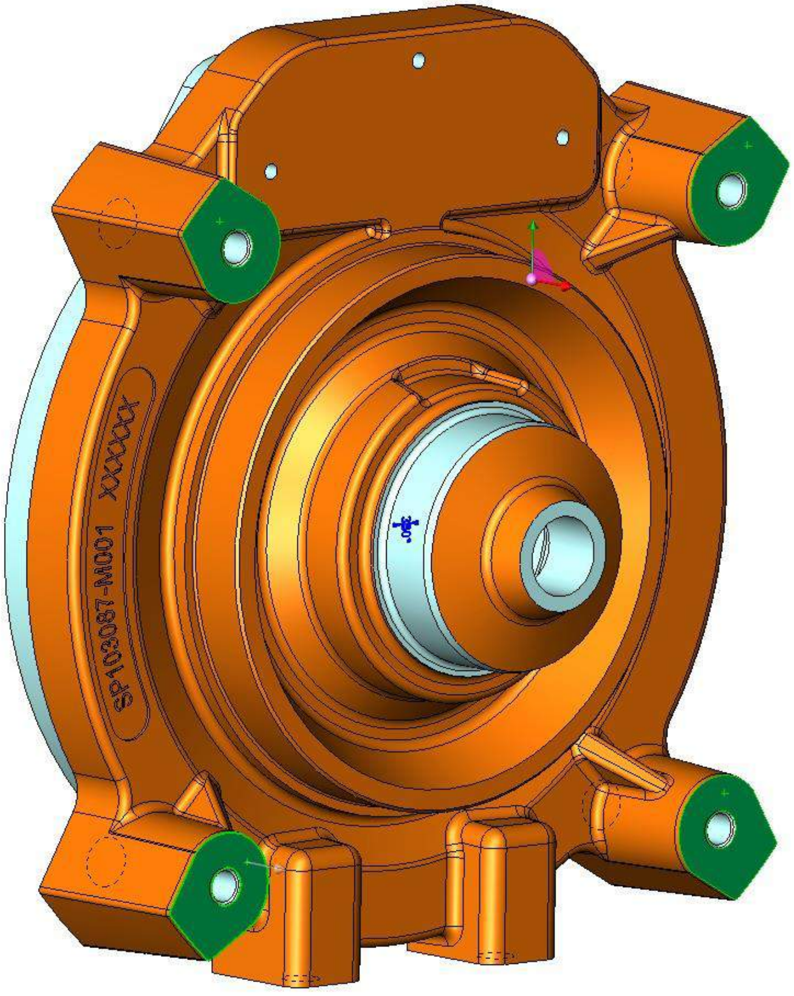
California has been using active Vapour recovery since the 1970's

A Rubber boot around the nozzle helps capture the expelled fumes

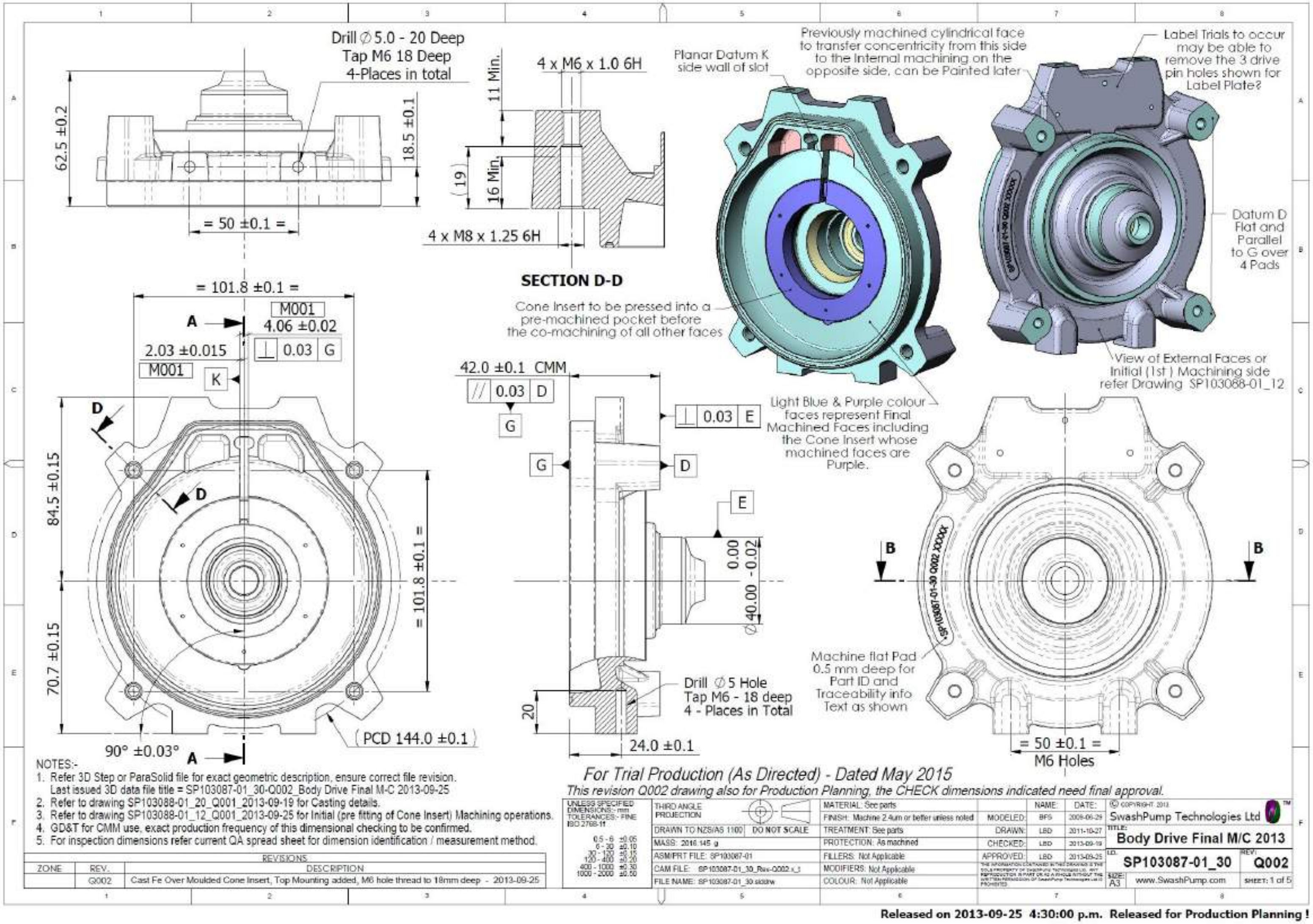


QA - Body Drive Motor Mount, Parallel faces



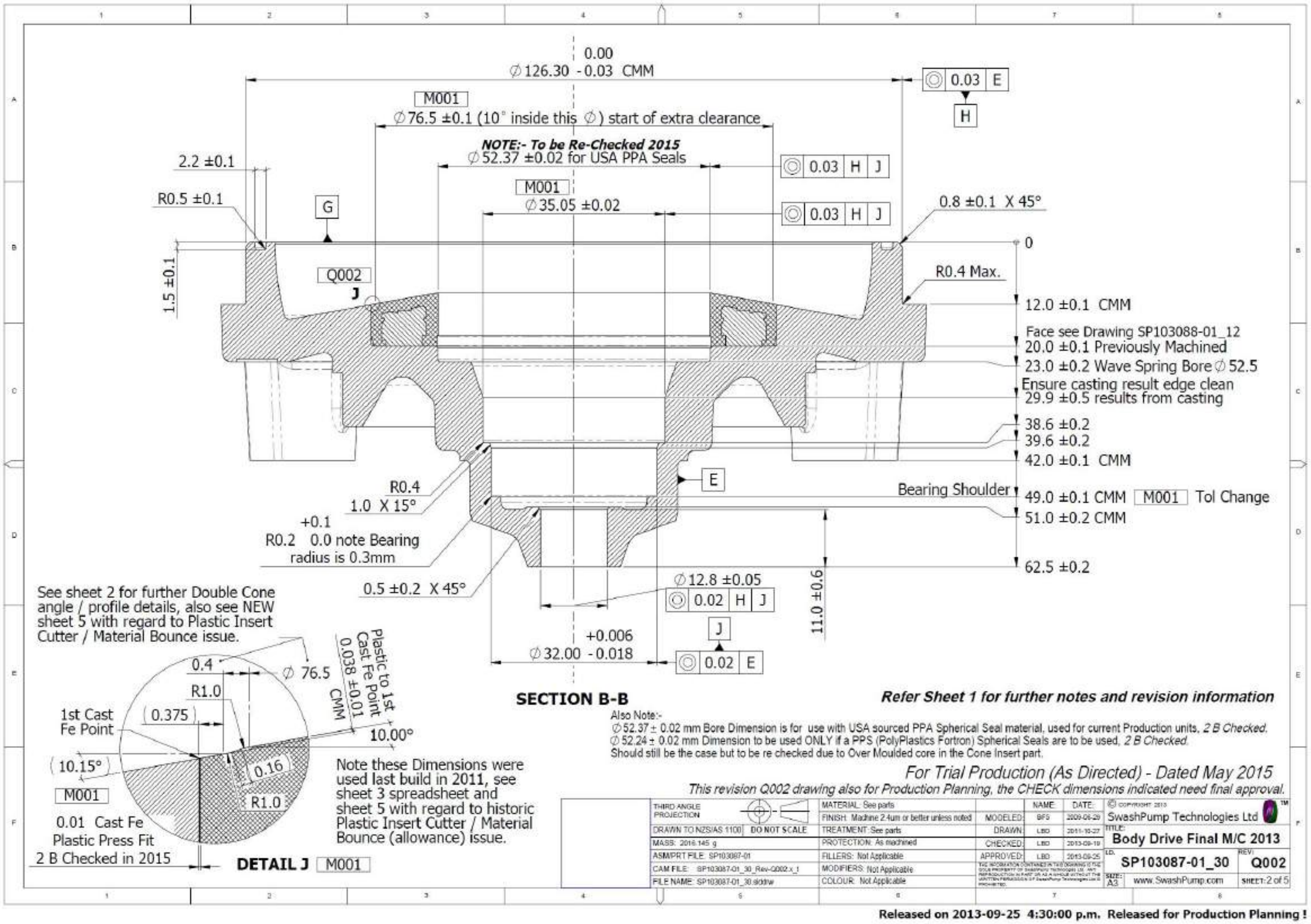


Drawings & QA



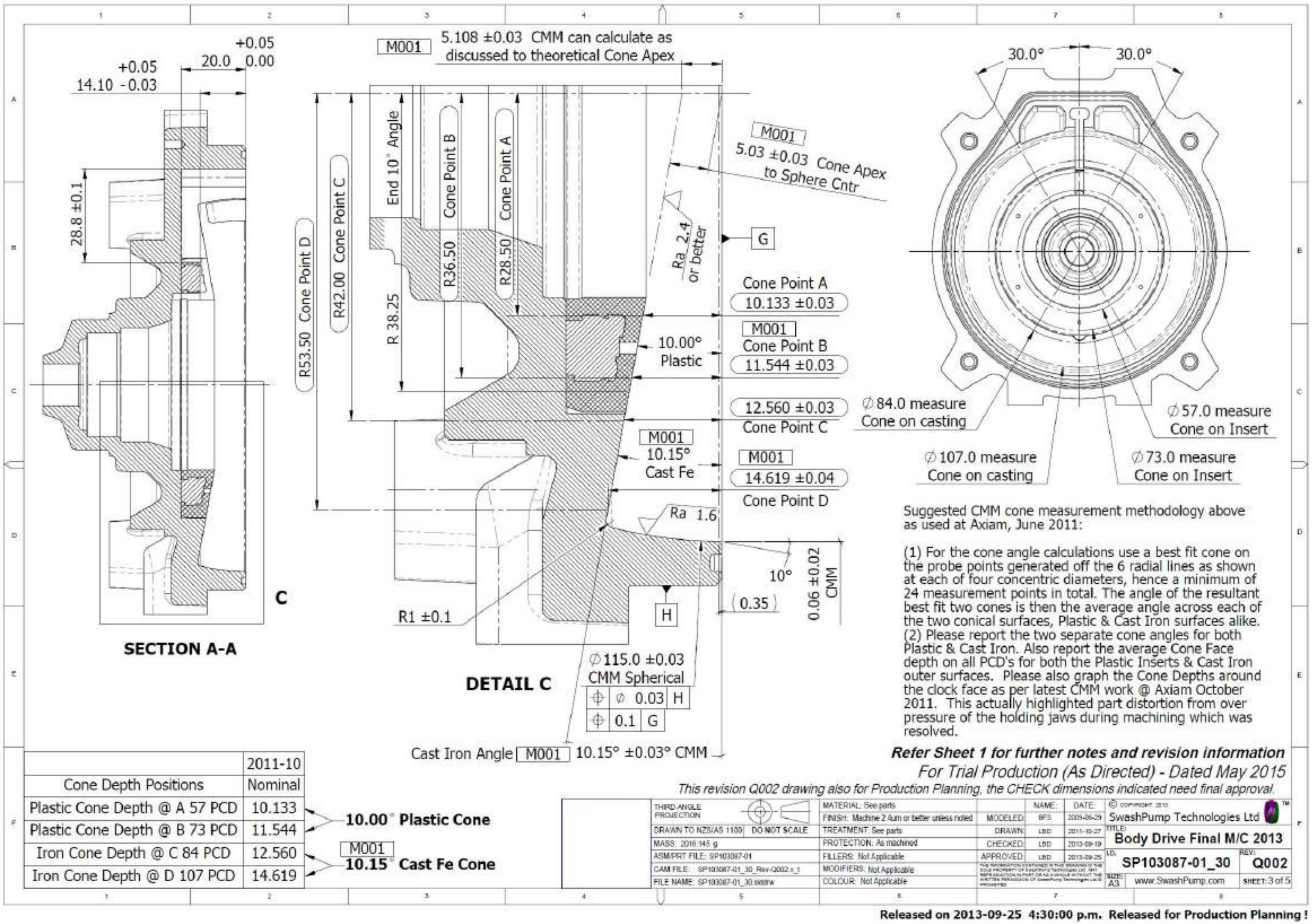
Drill ∅5.0 - 20 Deep
Tap M6 18 Deep
4-Places in total
62.5 ±0.2
18.5 ±0.1
= 50 ±0.1 =
11 Min.
4 x M6 x 1.0 6H
(19)
16 Min.
4 x M8 x 1.25 6H
SECTION D-D
Cone Insert to be pressed into a pre-machined pocket before the co-machining of all other faces
Planar Datum K side wall of slot
Previously machined cylindrical face to transfer concentricity from this side to the Internal machining on the opposite side, can be Painted later
Label Trials to occur may be able to remove the 3 drive pin holes shown for Label Plate?
Datum D Flat and Parallel to G over 4 Pads
View of External Faces or Initial (1st) Machining side refer Drawing SP103088-01_12
Light Blue & Purple colour faces represent Final Machined Faces including the Cone Insert whose machined faces are Purple.
= 101.8 ±0.1 =
M001
4.06 ±0.02
2.03 ±0.015
M001
0.03 G
K
42.0 ±0.1 CMM
0.03 D
G
0.03 E
D
E
84.5 ±0.15
70.7 ±0.15
= 101.8 ±0.1 =
0.00 - 0.02
∅40.00
Drill ∅5 Hole
Tap M6 - 18 deep
4 - Places in Total
20
24.0 ±0.1
Machine flat Pad 0.5 mm deep for Part ID and Traceability info Text as shown
PCD 144.0 ±0.1
90° ±0.03°
= 50 ±0.1 =
M6 Holes
NOTES:-
1. Refer 3D Step or ParaSolid file for exact geometric description, ensure correct file revision. Last issued 3D data file title = SP103087-01_30-Q002_Body Drive Final M-C 2013-09-25
2. Refer to drawing SP103088-01_20_Q001_2013-09-19 for Casting details.
3. Refer to drawing SP103088-01_12_Q001_2013-09-25 for Initial (pre fitting of Cone Insert) Machining operations.
4. GD&T for CMM use, exact production frequency of this dimensional checking to be confirmed.
5. For inspection dimensions refer current QA spread sheet for dimension identification / measurement method.
For Trial Production (As Directed) - Dated May 2015
This revision Q002 drawing also for Production Planning, the CHECK dimensions indicated need final approval.
REVISIONS
ZONE REV. DESCRIPTION
Q002 Cast Fe Over Moulded Cone Insert, Top Mounting added, M6 hole thread to 18mm deep - 2013-09-25
SwashPump Technologies Ltd
Body Drive Final M/C 2013
SP103087-01_30 Q002
www.SwashPump.com
SHEET: 1 of 5
Released on 2013-09-25 4:30:00 p.m. Released for Production Planning !

Drawings & QA



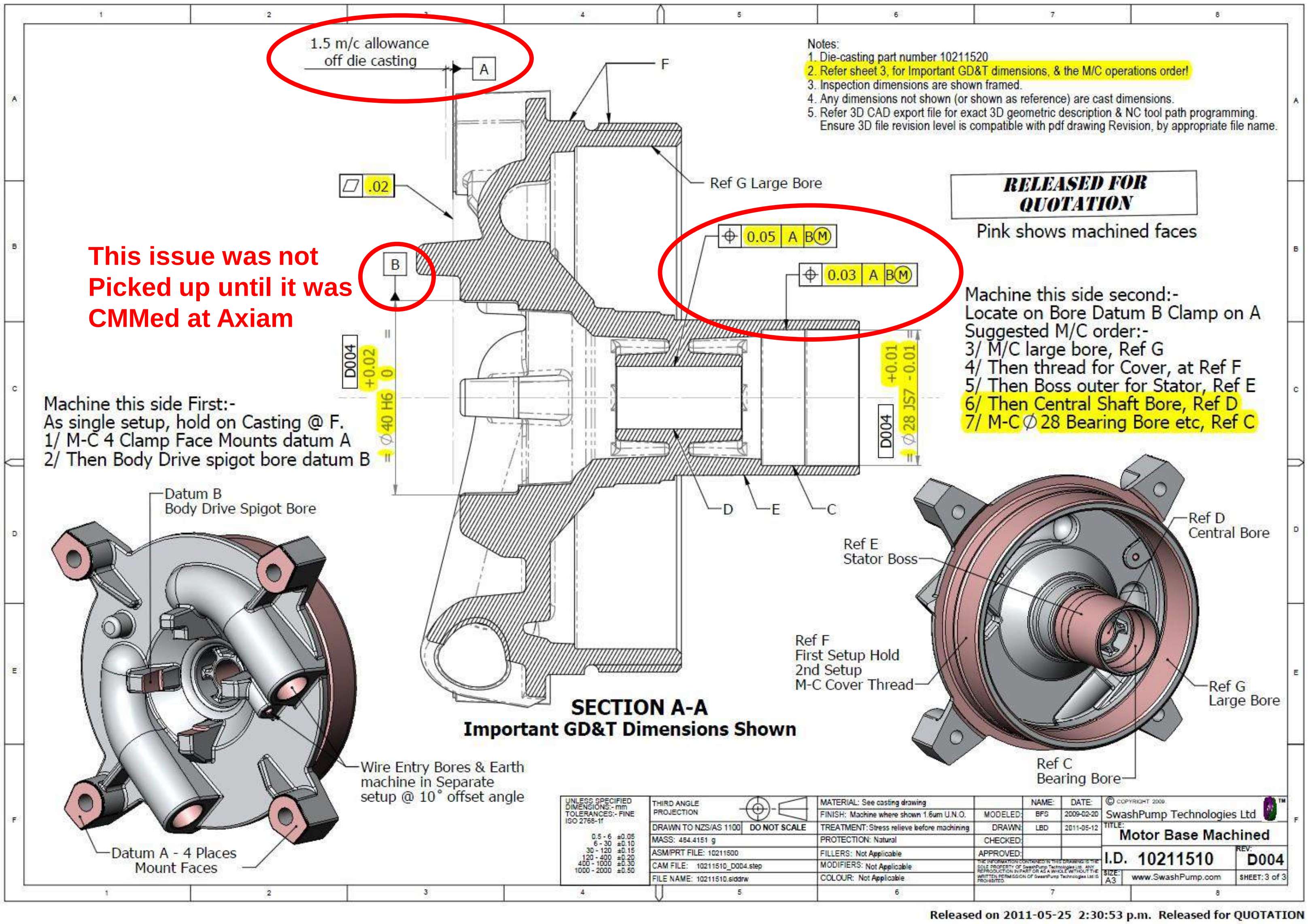
Ø 126.30 0.00 -0.03 CMM
0.03 E
H
M001
Ø 76.5 ±0.1 (10° inside this Ø) start of extra clearance
NOTE:- To be Re-Checked 2015
Ø 52.37 ±0.02 for USA PPA Seals
0.03 H J
2.2 ±0.1
R0.5 ±0.1
G
M001
Ø 35.05 ±0.02
0.03 H J
0.8 ±0.1 X 45°
0
1.5 ±0.1
Q002
J
R0.4 Max.
12.0 ±0.1 CMM
Face see Drawing SP103088-01_12
20.0 ±0.1 Previously Machined
23.0 ±0.2 Wave Spring Bore Ø 52.5
Ensure casting result edge clean
29.9 ±0.5 results from casting
38.6 ±0.2
39.6 ±0.2
42.0 ±0.1 CMM
E
R0.4
1.0 X 15°
Bearing Shoulder
49.0 ±0.1 CMM M001 Tol Change
51.0 ±0.2 CMM
R0.2 +0.1 0.0 note Bearing radius is 0.3mm
62.5 ±0.2
0.5 ±0.2 X 45°
Ø 12.8 ±0.05
0.02 H J
11.0 ±0.6
See sheet 2 for further Double Cone angle / profile details, also see NEW sheet 5 with regard to Plastic Insert Cutter / Material Bounce issue.
J
Ø 32.00 +0.006 -0.018
0.02 E
0.4
Ø 76.5
Plastic to 1st Cast Fe Point
Ø 0.038 ±0.01 CMM
R1.0
1st Cast Fe Point
0.375
10.00°
SECTION B-B
Refer Sheet 1 for further notes and revision information
Also Note:-
Ø 52.37 ± 0.02 mm Bore Dimension is for use with USA sourced PPA Spherical Seal material, used for current Production units, 2 B Checked.
Ø 52.24 ± 0.02 mm Dimension to be used ONLY if a PPS (PolyPlastics Fortron) Spherical Seals are to be used, 2 B Checked.
Should still be the case but to be re checked due to Over Moulded core in the Cone Insert part.
10.15°
0.16
M001
R1.0
0.01 Cast Fe Plastic Press Fit
2 B Checked in 2015
Note these Dimensions were used last build in 2011, see sheet 3 spreadsheet and sheet 5 with regard to historic Plastic Insert Cutter / Material Bounce (allowance) issue.
For Trial Production (As Directed) - Dated May 2015
This revision Q002 drawing also for Production Planning, the CHECK dimensions indicated need final approval.
DETAIL J M001
THIRD ANGLE PROJECTION
DRAWN TO NZS/AS 1100 DO NOT SCALE
MATERIAL: See parts
FINISH: Machine 2.4um or better unless noted
TREATMENT: See parts
PROTECTION: As machined
FILLERS: Not Applicable
MODIFIERS: Not Applicable
COLOUR: Not Applicable
SwashPump Technologies Ltd
Body Drive Final M/C 2013
SP103087-01_30
Q002
www.SwashPump.com
SHEET: 2 of 5
Released on 2013-09-25 4:30:00 p.m. Released for Production Planning !

Drawings & QA



M001 5.108 ±0.03 CMM can calculate as discussed to theoretical Cone Apex
M001 5.03 ±0.03 Cone Apex to Sphere Cntr
30.0°
30.0°
+0.05
20.0 0.00
+0.05
14.10 -0.03
28.8 ±0.1
End 10° Angle
Cone Point B
Cone Point A
Cone Point C
R42.00
R53.50 Cone Point D
R 38.25
R36.50
R28.50
Ra 2.4 or better
G
Cone Point A
10.133 ±0.03
M001
Cone Point B
11.544 ±0.03
10.00° Plastic
12.560 ±0.03
Cone Point C
M001
10.15° Cast Fe
M001
14.619 ±0.04
Cone Point D
Ra 1.6
10°
(0.35)
0.06 ±0.02 CMM
H
R1 ±0.1
C
SECTION A-A
DETAIL C
Ø115.0 ±0.03 CMM Spherical
Ø 0.03 H
0.1 G
Cast Iron Angle M001 10.15° ±0.03° CMM
Ø84.0 measure Cone on casting
Ø57.0 measure Cone on Insert
Ø107.0 measure Cone on casting
Ø73.0 measure Cone on Insert
Suggested CMM cone measurement methodology above as used at Axiam, June 2011:
(1) For the cone angle calculations use a best fit cone on the probe points generated off the 6 radial lines as shown at each of four concentric diameters, hence a minimum of 24 measurement points in total. The angle of the resultant best fit two cones is then the average angle across each of the two conical surfaces, Plastic & Cast Iron surfaces alike.
(2) Please report the two separate cone angles for both Plastic & Cast Iron. Also report the average Cone Face depth on all PCD's for both the Plastic Inserts & Cast Iron outer surfaces. Please also graph the Cone Depths around the clock face as per latest CMM work @ Axiam October 2011. This actually highlighted part distortion from over pressure of the holding jaws during machining which was resolved.
Refer Sheet 1 for further notes and revision information
For Trial Production (As Directed) - Dated May 2015
This revision Q002 drawing also for Production Planning, the CHECK dimensions indicated need final approval.
Cone Depth Positions | 2011-10 Nominal
Plastic Cone Depth @ A 57 PCD | 10.133
Plastic Cone Depth @ B 73 PCD | 11.544
Iron Cone Depth @ C 84 PCD | 12.560
Iron Cone Depth @ D 107 PCD | 14.619
10.00° Plastic Cone
M001 10.15° Cast Fe Cone
THIRD ANGLE PROJECTION
DRAWN TO NZS/AS 1100
DO NOT SCALE
MATERIAL: See parts
FINISH: Machine 2.4um or better unless noted
TREATMENT: See parts
PROTECTION: As machined
FILLERS: Not Applicable
MODIFIERS: Not Applicable
COLOUR: Not Applicable
SwashPump Technologies Ltd
Body Drive Final M/C 2013
SP103087-01_30
Q002
www.SwashPump.com
SHEET: 3 of 5
Released on 2013-09-25 4:30:00 p.m. Released for Production Planning !

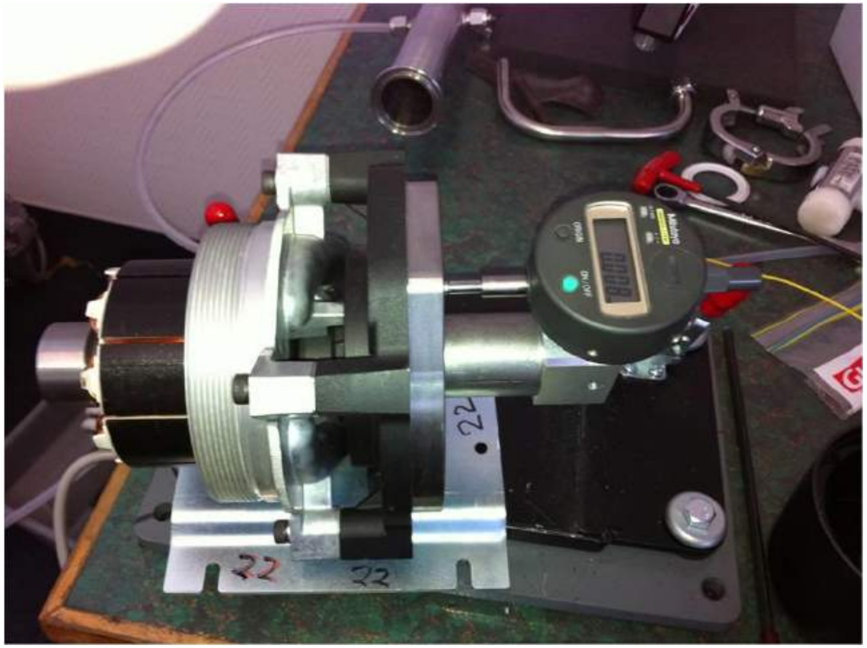
WDT Motor Base Bearing Concentricity Problem



CMM of WDT Motor Base Bearing

Drive Side Body / Motor Alignment check

We made an Alignment verification Jig at Axiam, so we could double check without CMM



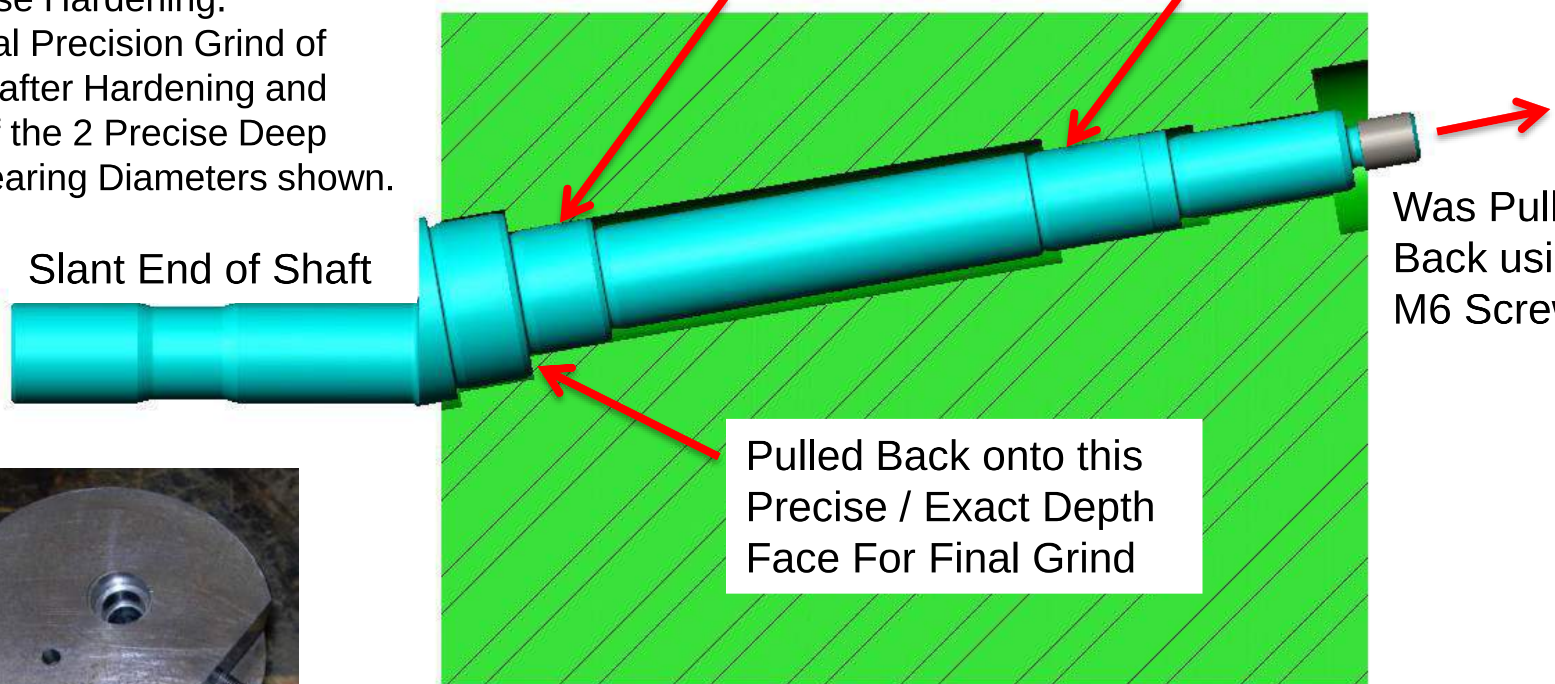
The Manual Drive Shaft Jig(s) in Cross Section

Full Production manufacture would be on an NC grinder with hydraulic self centring collets

Note two Jigs are currently used:-
1st for Initial Turning of Slant End Before Case Hardening.
2nd for Final Precision Grind of Slant End after Hardening and grinding of the 2 Precise Deep Groove Bearing Diameters shown.

2 x Precision Locating Bores @ the Deep Groove Bearing Positions

Slant End of Shaft

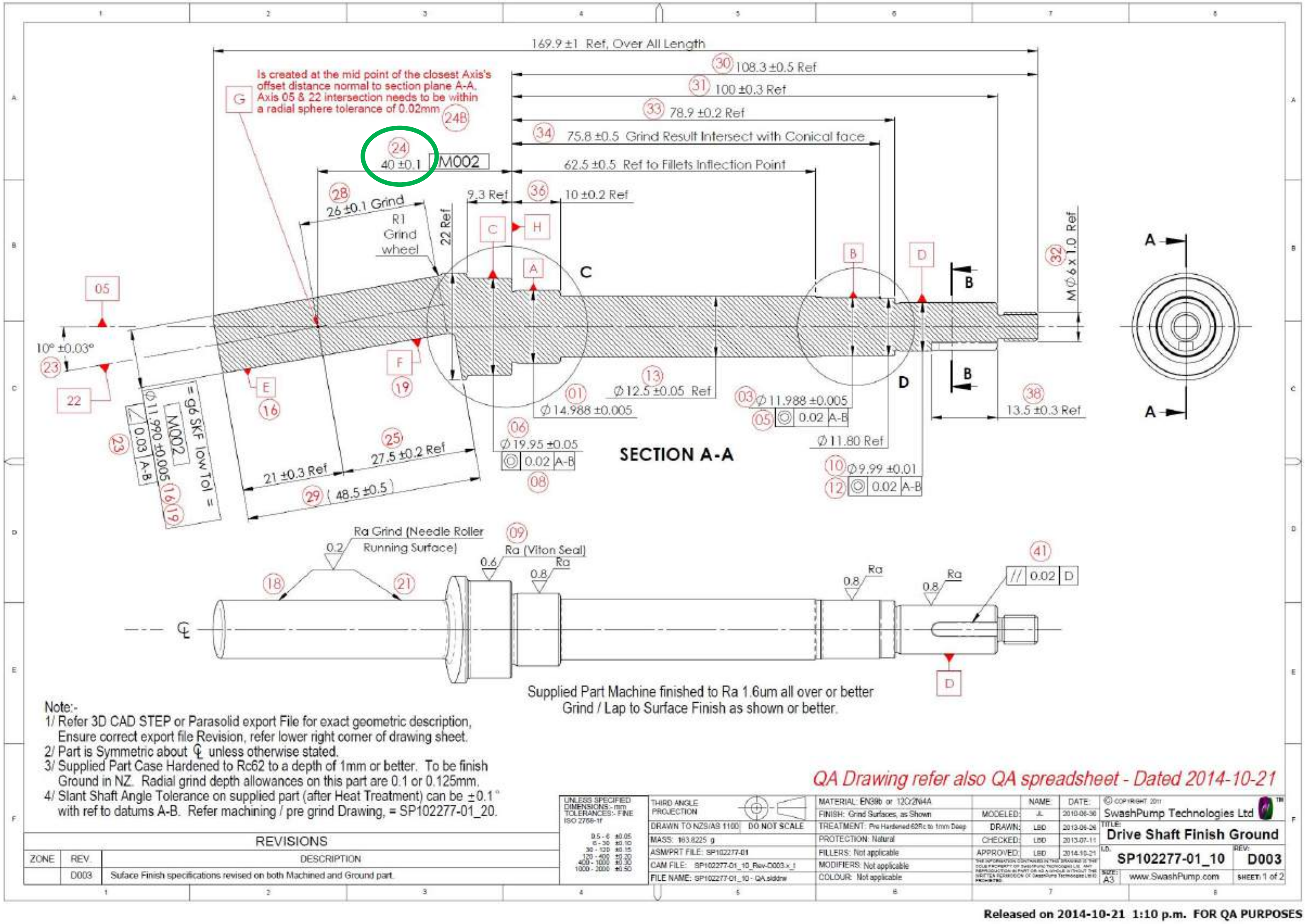


Was Pulled Back using M6 Screw

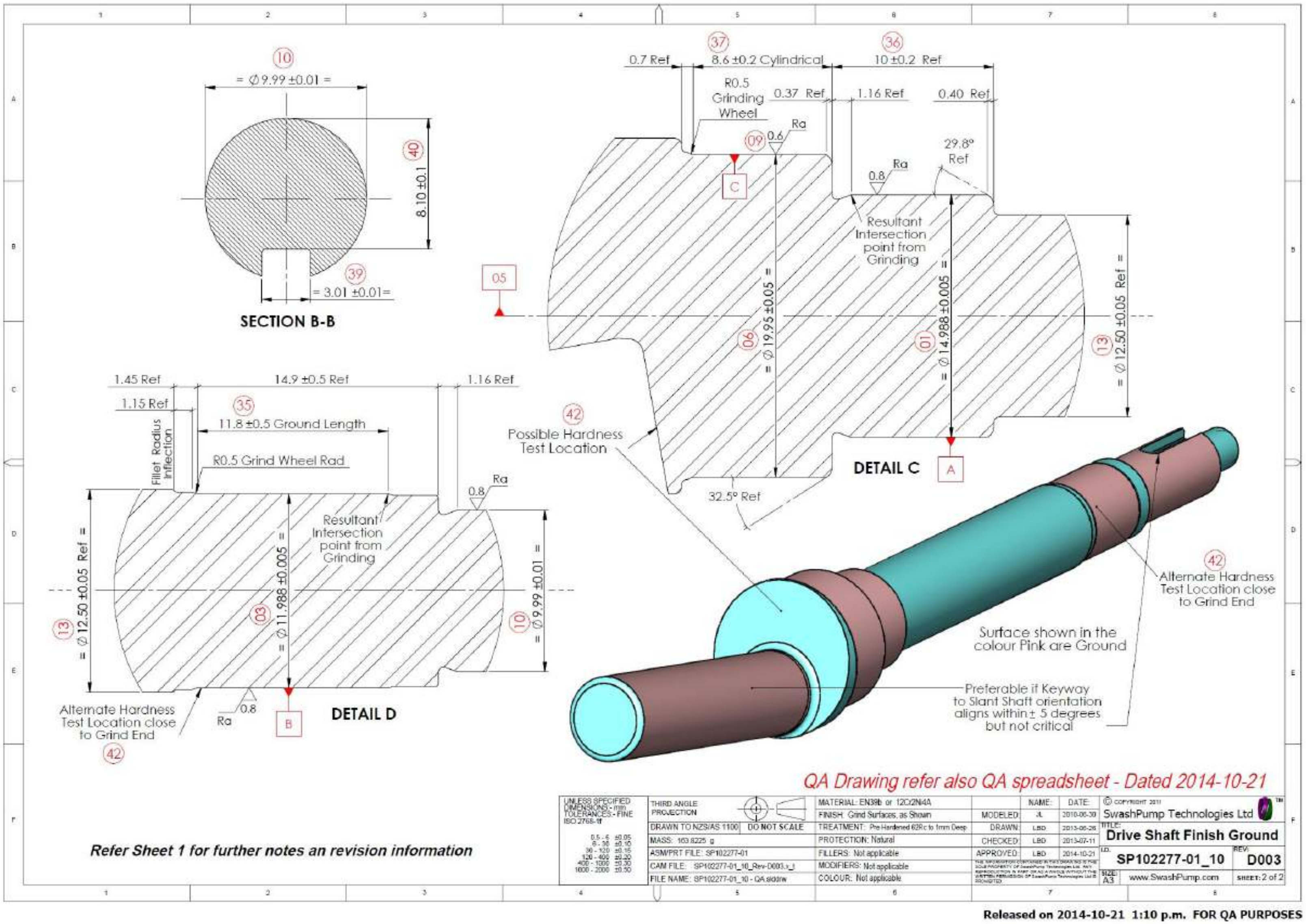
Pulled Back onto this Precise / Exact Depth Face For Final Grind

SECTION A-A

Shaft also needed QA with CMM



Shaft also needed QA with CMM



Detailed Measurement CMM Report, Body Drive

Name:		Batch:	ACCEPTED / REJECTED / CONCESSED (delete as applicable)
Date:			

DATA

#		LSL	MID	USL	Predicated LL	UL	Cpk	Cp	Mean	Std Dev	Min	Max
1	Total body length	62.300	62.500	62.700	62.423	62.591	2.306	2.388	62.507	0.028	62.458	62.535
2	M6 Thread length	10.000	11.000	12.000	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
3	M8 Thread length	16.000	16.500	17.000	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
4	M8 thread to 6H											
5	Divider slot side to centre	2.015	2.025	2.035	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
6	Divider slot width	4.030	4.050	4.070	4.029	4.076	0.735	0.856	4.053	0.008	4.030	4.064
7	Divider slot perp to G			0.020		0.017		0.822	0.005	0.004	0.000	0.015
8	Divider slot depth to G	20.000	20.025	20.050	19.972	20.057	0.341	0.585	20.015	0.014	19.985	20.032
9	Divider slot height	66.300	66.400	66.500	66.278	66.427	0.707	1.349	66.352	0.025	66.302	66.385
10	G to D distance	41.900	42.000	42.100	41.878	42.053	0.701	1.141	41.966	0.029	41.911	42.002
11	G to D parallel			0.030		0.119		0.201	0.045	0.025	0.000	0.078
12	Motor spigot dia E	39.980	39.990	40.000	39.979	40.004	0.691	0.807	39.991	0.004	39.986	39.998
13	main spigot dia H	126.270	126.285	126.300	126.248	126.312	0.312	0.468	126.280	0.011	126.255	126.299
14	H conc to E			0.020		0.044		0.552	0.026	0.006	0.012	0.035
15	Bearing Bore dia J	32.000	32.008	32.016	31.981	32.020	0.037	0.414	32.001	0.006	31.990	32.013
16	J conc to E			0.020		0.026		0.714	0.012	0.005	0.005	0.021
17	Viton seal bore dia	35.000	35.020	35.040	34.982	35.019	0.043	1.089	35.001	0.006	34.991	35.012
18	Viton seal bore conc to J			0.030		0.012		1.929	0.004	0.003	0.001	0.011
19	Spherical seal bore diameter	52.350	52.370	52.390	52.340	52.401	0.649	0.655	52.370	0.010	52.338	52.387
20	Spherical seal conc to J			0.030		0.035		0.780	0.016	0.006	0.006	0.029
21	Shaft hole bore diameter	12.750	12.800	12.850	12.733	12.861	0.728	0.790	12.797	0.021	12.766	12.873
22	Shaft hole conc to J			0.020		0.013		1.278	0.005	0.003	0.001	0.010
23	Spigot step to face plane G	11.900	12.000	12.100	11.911	12.036	1.182	1.607	11.974	0.021	11.921	11.991
24	Bearing shoulder to G	48.950	49.000	49.050	48.933	49.048	0.701	0.866	48.990	0.019	48.956	49.019
25	Shaft hole entry face to G	50.800	51.000	51.200	50.805	51.211	0.940	0.985	51.008	0.068	50.931	51.177
26	Cone depth at 94mm diameter	12.524	12.544	12.564	12.489	12.589	0.297	0.405	12.539	0.016	12.504	12.566
27	Cone angle (24 points)	159.970	160.000	160.030	159.873	160.242	-0.147	0.163	160.057	0.062	159.986	160.179
28	Main sphere diameter	114.980	115.000	115.020	114.966	115.016	0.438	0.800	114.991	0.008	114.964	115.001
29	Main sphere conc to H			0.030		0.024		1.068	0.010	0.005	0.003	0.019
30	Main sphere centre to G			0.100		0.116		0.575	0.029	0.029	0.001	0.110
31	Sphere edge chamfer	0.040	0.060	0.080	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
32a	Left top face height to G	73.630	73.650	73.670	73.619	73.663	0.409	0.899	73.641	0.007	73.623	73.653
32b	Right top face height to G	73.630	73.650	73.670	73.626	73.661	0.779	1.130	73.644	0.006	73.631	73.653
33	Left point at 55mm	37.640	37.660	37.680	37.623	37.687	0.406	0.630	37.655	0.011	37.634	37.671
34	Left face angle	123.470	123.500	123.530	123.453	123.510	0.398	1.054	123.481	0.009	123.466	123.499
35	Right point at 55mm	37.640	37.660	37.680	37.605	37.657	-0.350	0.763	37.631	0.009	37.612	37.645
36	Right face angle	56.470	56.500	56.530	56.486	56.532	0.655	1.090	56.512	0.009	56.490	56.527
37	Foot plane height to centre	70.600	70.700	70.800	70.703	70.749	3.243	4.371	70.726	0.008	70.714	70.745
38	Foot plane angle to K	89.970	90.000	90.030	89.999	90.003	12.874	12.887	90.000	0.001	89.999	90.002
39	Plane D perp to E			0.020		0.022		0.845	0.010	0.004	0.001	0.014
40	Wave spring face to G	22.850	23.000	23.150	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
41	Top left spigot radius	9.850	9.900	9.950	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
42	Top right spigot radius	9.850	9.900	9.950	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000	0.000
43	Top spigot face perp to K			0.040		0.014		2.170	0.005	0.003	0.000	0.011
44	Cone apex to G	5.118	5.148	5.178	5.079	5.210	0.402	0.456	5.144	0.022	5.105	5.189
45	Cone conicity			0.000		0.056		0.000	0.036	0.007	0.019	0.049

#	serial 1	serial 2	serial 3	serial 4	serial 5	serial 6	serial 7	serial 8	serial 9	serial 10
1	62.471	62.458	62.464	62.465	62.509	62.516	62.468	62.479	62.472	62.514
2										
3										
4										
5										
6	4.057	4.047	4.046	4.055	4.056	4.062	4.030	4.052	4.055	4.054
7	0.002	0.003	0.001	0.005	0.003	0.010	0.000	0.001	0.008	0.009
8	19.985	19.991	19.992	19.986	20.009	20.014	19.998	20.021	20.014	20.032
9	66.302	66.307	66.317	66.356	66.334	66.306	66.360	66.336	66.350	66.358
10	41.921	41.911	41.935	41.929	41.972	41.971	41.931	41.929	41.925	41.970
11	0.000	0.000	0.000	0.047	0.037	0.000	0.042	0.055	0.071	0.041
12	39.990	39.992	39.990	39.990	39.997	39.997	39.991	39.998	39.995	39.990
13	126.264	126.265	126.292	126.283	126.265	126.272	126.290	126.267	126.288	126.282
14	0.012	0.020	0.029	0.001	0.027	0.029	0.035	0.022	0.025	0.032
15	31.992	31.990	32.003	32.010	32.005	31.998	32.000	31.991	32.002	32.004
16	0.008	0.007	0.013	0.014	0.013	0.015	0.013	0.006	0.005	0.010
17	34.991	34.993	35.004	35.012	35.006	34.998	35.002	34.992	35.005	35.003
18	0.003	0.002	0.002	0.002	0.007	0.006	0.001	0.005	0.002	0.004
19	52.351	52.338	52.375	52.376	52.373	52.372	52.372	52.370	52.387	52.378
20				0.009	0.012		0.007	0.006	0.010	0.018
21	12.766	12.775	12.801	12.813	12.794	12.768	12.873	12.787	12.807	12.794
22	0.009	0.007	0.005	0.005	0.007	0.005	0.005	0.008	0.003	0.001
23	11.969	11.970	11.980	11.972	11.974	11.977	11.921	11.927	11.927	11.972
24	48.971	48.990	48.975	48.976	48.973	48.974	48.958	48.961	48.956	48.995
25	51.151	50.990	51.177	50.983	50.980	50.991	50.931	50.932	50.934	50.988
26	12.530	12.534	12.525	12.527	12.528	12.538	12.514	12.505	12.504	12.541
27	160.125	160.176	160.177	160.179	160.124	160.098	160.056	160.048	160.081	160.058
28	114.980	114.964	114.987	114.984	114.989	114.987	114.984	114.996	114.996	115.000
29	0.005	0.008	0.003	0.004	0.004	0.008	0.007	0.011	0.011	0.011
30	0.025	0.059	0.003	0.016	0.010	0.010	0.072	0.110	0.078	0.056
31										
32a	73.625	73.623	73.642	73.640	73.631	73.633	73.645	73.645	73.644	73.640
32b	73.634	73.631	73.646	73.645	73.636	73.641	73.653	73.639	73.646	73.650
33	37.634	37.638	37.638	37.655	37.640	37.642	37.661	37.655	37.663	37.654
34	123.470	123.473	123.475	123.483	123.476	123.477	123.488	123.498	123.481	123.467
35	37.641	37.643	37.637	37.645	37.627	37.644	37.624	37.615	37.631	37.622
36	56.508	56.510	56.505	56.490	56.507	56.515	56.496	56.524	56.516	56.500
37	70.722	70.718	70.723	70.738	70.727	70.716	70.745	70.730	70.726	70.722
38	90.000	90.000	90.001	90.001	89.999	90.001	90.000	90.001	90.000	90.001
39				0.011	0.014		0.012	0.004	0.011	0.004
40										
41										
42										
43	0.009	0.008	0.007	0.006	0.005	0.007	0.008	0.006	0.002	0.011
44	5.166	5.189	5.181	5.184	5.100	5.148	5.121	5.105	5.116	5.143
45	0.022	0.019	0.036	0.039	0.043	0.038	0.037	0.034	0.031	0.043

#	serial 11	serial 12	serial 13	serial 14	serial 15	serial 16	serial 17	serial 18	serial 19
1	62.521	62.525	62.527	62.528	62.530	62.528	62.531	62.528	62.529
2									
3									
4									
5									
6	4.061	4.064	4.060	4.063	4.059	4.060	4.047	4.043	4.047
7	0.003	0.001	0.012	0.003	0.006	0.003	0.008	0.002	0.002
8	20.023	20.023	20.023	20.018	20.018	20.022	20.030	20.026	20.025
9	66.362	66.367	66.358	66.385	66.385	66.371	66.370	66.365	66.363
10	41.984	41.986	41.982	41.985	42.002	41.992	41.994	41.992	41.982
11	0.075	0.058	0.052	0.065	0.070	0.039	0.049	0.065	0.034
12	39.996	39.990	39.986	39.996	39.986	39.987	39.987	39.990	39.991
13	126.289	126.289	126.294	126.279	126.279	126.273	126.281	126.277	126.288
14	0.033	0.028	0.027	0.026	0.028	0.018	0.035	0.032	0.033
15	32.002	32.004	32.004	32.013	31.998	32.010	31.999	31.994	31.996
16	0.020	0.015	0.007	0.011	0.011	0.011	0.006	0.019	0.015
17	34.995	35.006	34.999	35.010	35.000	35.009	35.000	34.996	34.995
18	0.004	0.006	0.004	0.011	0.002	0.004	0.004	0.005	0.001
19	52.374	52.378	52.374	52.381	52.374	52.378	52.365	52.366	52.360
20	0.024	0.020	0.022	0.016	0.009	0.016	0.023	0.019	0.020
21	12.803	12.807	12.813	12.805	12.798	12.785	12.798	12.782	12.790
22	0.010	0.005	0.007	0.004	0.009	0.001	0.004	0.005	0.003
23	11.984	11.985	11.984	11.979	11.989	11.988	11.991	11.987	11.987
24	49.019	49.006	49.005	49.007	49.008	49.004	49.007	49.005	49.002
25	50.983	51.000	50.989	51.025	50.982	50.990	51.161	50.987	51.001
26	12.562	12.556	12.541	12.554	12.547	12.548	12.542	12.547	12.549
27	160.044	160.025	160.012	160.012	160.029	160.033	160.029	160.005	159.986
28	114.996	114.993	114.994	114.995	114.981	115.000	114.994	114.998	114.999
29	0.013	0.011	0.004	0.009	0.010	0.006	0.016	0.019	0.019
30	0.029	0.002	0.007	0.021	0.020	0.001	0.032	0.013	0.017
31									
32a	73.646	73.646	73.653	73.648	73.644	73.638	73.644	73.644	73.647
32b	73.649	73.648	73.651	73.642	73.639	73.639	73.645	73.640	73.647
33	37.668	37.662	37.665	37.653	37.653	37.650	37.663	37.656	37.659
34	123.481	123.481	123.493	123.488	123.484	123.485	123.482	123.406	123.499
35	37.633	37.629	37.631	37.624	37.612	37.631	37.630	37.636	37.640
36	56.512	56.516	56.522	56.517	56.518	56.516	56.521	56.527	56.521
37	70.718	70.723	70.723	70.735	70.735	70.734	70.728	70.725	70.714
38	89.999	90.000	90.001	89.999	90.002	89.999	90.001	90.000	89.999
39	0.011	0.012	0.013	0.006	0.011	0.010	0.001	0.014	0.014
40									
41									
42									
43	0.003	0.002	0.002	0.006	0.005	0.001	0.001	0.004	0.000
44	5.151	5.148	5.138	5.138	5.145	5.141	5.133	5.130	5.122
45	0.040	0.038	0.049	0.041	0.038	0.032	0.033	0.041	0.039

#	serial 20	serial 21	serial 22	serial 23	serial 24	serial 25	serial 26	serial 27	serial 28
1	62.529	62.535	62.524	62.532	62.531	62.531	62.534	62.526	62.528
2									
3									
4									
5									
6	4.047	4.054	4.057	4.052	4.054	4.054	4.054	4.063	4.049
7	0.015	0.005	0.000	0.003	0.005	0.001	0.005	0.000	0.010
8	20.025	20.022	20.023	20.012	20.019	20.024	20.031	20.025	20.026
9	66.377	66.361	66.366	66.364	66.385	66.374	66.375	66.357	66.361
10	41.989	41.988	41.979	41.990	41.996	41.991	41.986	41.991	41.988
11	0.063	0.041	0.078	0.046	0.053	0.063	0.040	0.065	0.046
12	39.992	39.987	39.986	39.987	39.993	39.986	39.987	39.992	39.992
13	126.281	126.283	126.281	126.299	126.280	126.282	126.291	126.272	126.285
14	0.020	0.019	0.018	0.020	0.027	0.030	0.001	0.025	0.028
15	31.997	31.994	32.009	32.015	32.006	31.997	32.004	32.001	31.997
16	0.007	0.012	0.021	0.011	0.007	0.006	0.003	0.007	0.003
17	34.996	34.998	35.009	35.007	35.006	35.000	35.002	35.000	34.997
18	0.006	0.005	0.010	0.007	0.003	0.006	0.003	0.015	0.006
19	52.367	52.374	52.368	52.371	52.375	52.372	52.374	52.376	52.374
20	0.017	0.014	0.029	0.016	0.009	0.012	0.013	0.017	0.013
21	12.789	12.786	12.793	12.803	12.793	12.784	12.799	12.778	12.795
22	0.003	0.007	0.010	0.009	0.005	0.004	0.000	0.006	0.002
23	11.989	11.984	11.962	11.979	11.980	11.986	11.987	11.987	11.989
24	49.003	49.006	49.000	49.008	49.007	49.004	49.006	49.002	49.005
25	51.024	50.988	50.980	50.992	50.980	50.981	51.027	50.994	50.981
26	12.546	12.566	12.558	12.546	12.554	12.557	12.556	12.555	12.554
27	159.988	159.988	160.018	160.083	160.064	160.042	160.003	160.017	160.032
28	114.993	114.996	115.001	114.982	114.989	114.993	114.993	114.989	114.995
29	0.010	0.013	0.013	0.012	0.012	0.016	0.013	0.011	0.009
30	0.003	0.015	0.044	0.000	0.001	0.020	0.011	0.039	0.018
31									
32a	73.642	73.639	73.648	73.649	73.645	73.633	73.649	73.640	73.653
32b	73.644	73.648	73.649	73.648	73.643	73.638	73.655	73.640	73.646
33	37.661	37.671	37.657	37.663	37.648	37.648	37.671	37.649	37.651
34	123.475	123.466	123.472	123.493	123.487	123.481	123.468	123.468	123.492
35	37.630	37.626	37.629	37.630	37.636	37.612	37.630	37.618	37.629
36	56.509	56.510	56.510	56.511	56.519	56.512	56.619	56.529	56.536
37	70.720	70.722	70.723	70.753	70.741	70.738	70.728	70.730	70.726
38	90.000	90.001	90.001	89.999	90.000	90.001	90.000	90.000	90.000
39	0.014	0.013	0.009	0.009	0.006	0.008	0.009	0.009	0.008
40							22.999	22.995	22.990
41							10.020	9.966	10.013
42							9.926	9.929	9.965
43	0.002	0.009	0.001	0.001	0.002	0.003	0.006	0.000	0.007
44	5.123	5.148	5.148	5.168	5.161	5.163	5.137	5.139	5.146
45	0.042	0.032	0.036	0.029	0.039	0.037	0.037	0.039	0.035

TUV Approvals

- First Pump to be certified to new EU legisation
- First **two sided pump** to be certified with Petrol instead of Air
- Certifications
  - Zephyr 2 Pump with 2x (burket control valves, OPW nozzles and PEC hoses)
  - Zephyr 2 Pump with 2x (burket control valves, Elaflex nozzles and PEC hoses)

Swash Vapor Recovery System (VRS)

Prototype

Production Unit

SwashPump (Pre) Production Products

Gas

Swash Vapor Recovery System (VRS)

Prototype

Production Unit

Liquid

Swash Fuel Pump System (FPS)
Petrol, Diesel, Bio Fuel

Prototype

Production Unit

SwashVRS - Petrol Vapour Recovery System

The End

TMI - beyond here

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Innovative Mechanical Engineering

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Summary

➲ Some countries vapor recovery legislation requires the vapour flow to be measured and compared to the volume of liquid dispensed to calculate the A/L ratio for each fill cycle.

Current monitored system

Pump	A/L	Monitoring	Hanging hardware
Vapour recovery Pump →	A/L valves →	Fafnir vapor flow Meters →	Pipework and nozzle
	Valve Controller	Meter Controller	



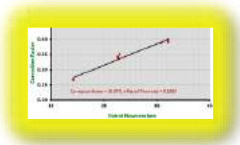

Pump	A/L	Monitoring	Hanging hardware
$500	$1500	$3000	

Cost for 2 fill points : $5000 (not including hanging hardware)

SPT / OPW monitored system

Pump	A/L	Monitoring	Hanging hardware
Swash Pump →	A/L valves →	Software →	Pipework and nozzle






Pump	A/L	Monitoring	Hanging hardware
$700	$200	Free – Included in controller	

Cost for 2 fill points : $900 (not including hanging hardware)

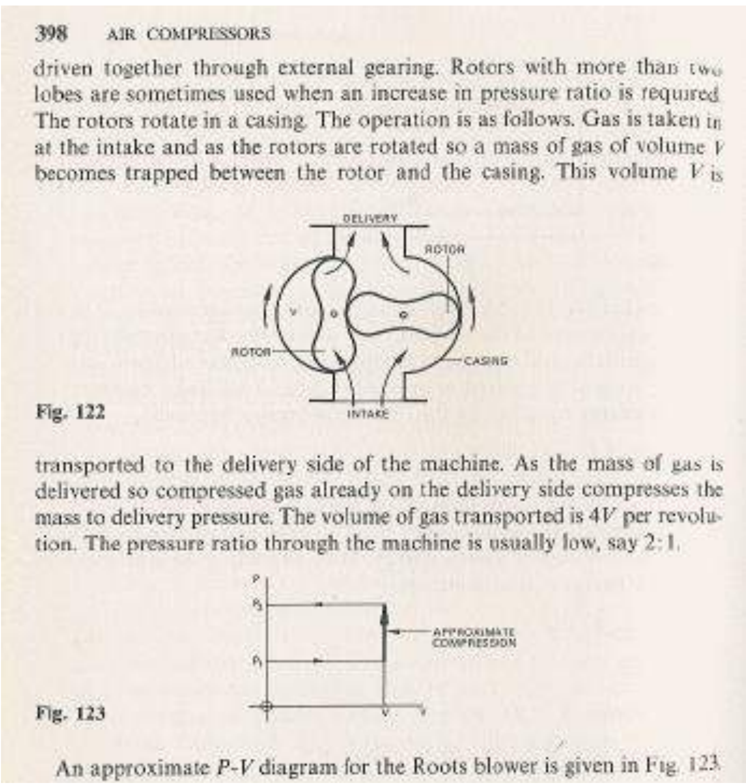
Superior Performance v Roots

Definition	SwashPumpTM
Dry Pump	Yes
RPM	Low i.e. 980 to 1440 for 4 or 6 pole synchronous motor speed
Scaleable	200-50,000 Nl/min 7-1750 ft3/min @ 500mbar
Thermo-dynamic Efficiency	>55% @ 500 mbar Adiabatic Reversible
Exhaust Temperature	< 92 C <194 F
Noise Level	< 85 dB(A)
Vibration	< 5.6 mm/s RMS <.02 ft/s RMS
Service Interval	Trunnion Maintenance approx 2000 hours

Test Rig & Dynamometer

Joel on PV for Roots Blower & Theory

- Joel, Roots Blower PV



398 AIR COMPRESSORS

driven together through external gearing. Rotors with more than two lobes are sometimes used when an increase in pressure ratio is required. The rotors rotate in a casing. The operation is as follows. Gas is taken in at the intake and as the rotors are rotated so a mass of gas of volume V becomes trapped between the rotor and the casing. This volume V is

Fig. 122

transported to the delivery side of the machine. As the mass of gas is delivered so compressed gas already on the delivery side compresses the mass to delivery pressure. The volume of gas transported is $4V$ per revolution. The pressure ratio through the machine is usually low, say 2:1.

Fig. 123

An approximate P-V diagram for the Roots blower is given in Fig. 123.

- Joel, Theoretical Compression

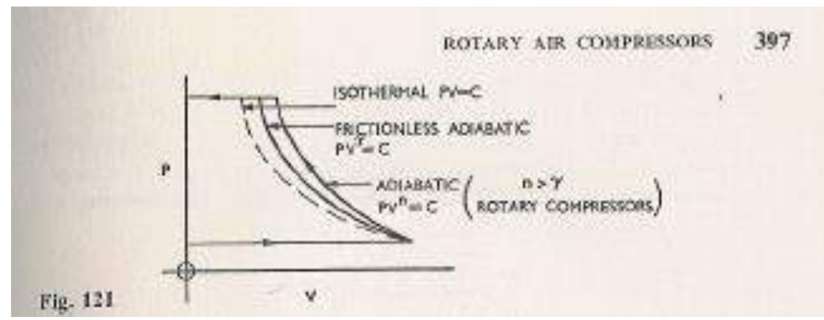


Fig. 121

Ideal SwashPump PV diagram, Closer to the Ideal Isentropic Process

Swashpump P2.5 ideal pv Diagram with non return valves on the outlet

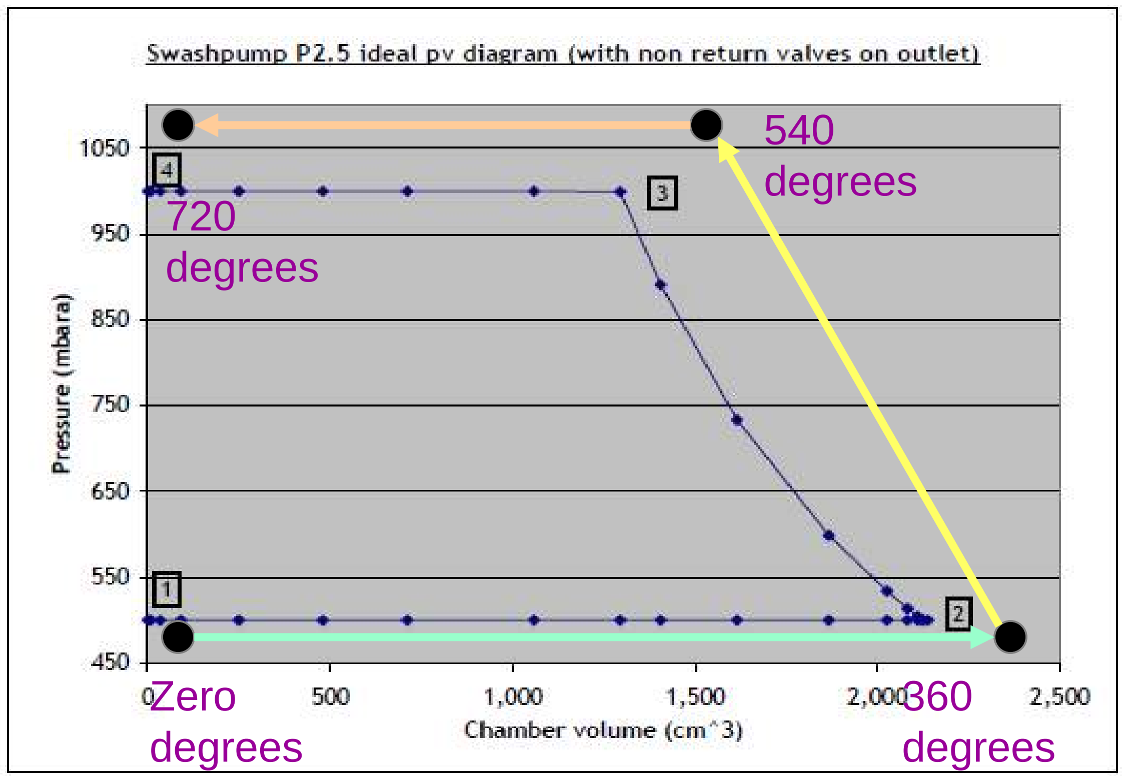
Swashpump Technologies Page 1 of 2

Author: Ben Smit 6/08/2007 Version: 1.0

Full pumping cycle

Shaft angle (Degrees)	Chamber volume (cm^3)	Pressure (mbara)
0	0	500
29	9	500
50	34	500
70	91	500
100	250	500
130	480	500
150	711	500
180	1,059	500
	1,295	500
210	1,406	500
240	1,615	500
260	1,867	500
290	2,026	500
310	2,083	500
329	2,110	500
340	2,124	500
360	2,138	500
380	2,124	500
389	2,110	504.7
410	2,083	513.8
430	2,026	534.2
460	1,867	598.9
490	1,615	733.7
510	1,406	890.9
	1,295	999.6
540	1,059	1000
570	711	1000
600	480	1000
620	250	1000
650	91	1000
670	34	1000
689	9	1000
720	0	1000

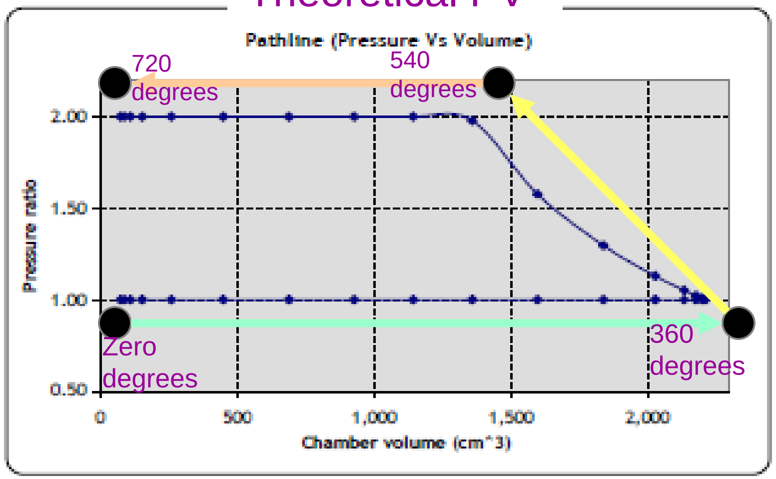
1 Intake cycle - inlet port open 2 Adiabatic compression $pv^{1.4}$ 3 Expulsion past the reed valves 4



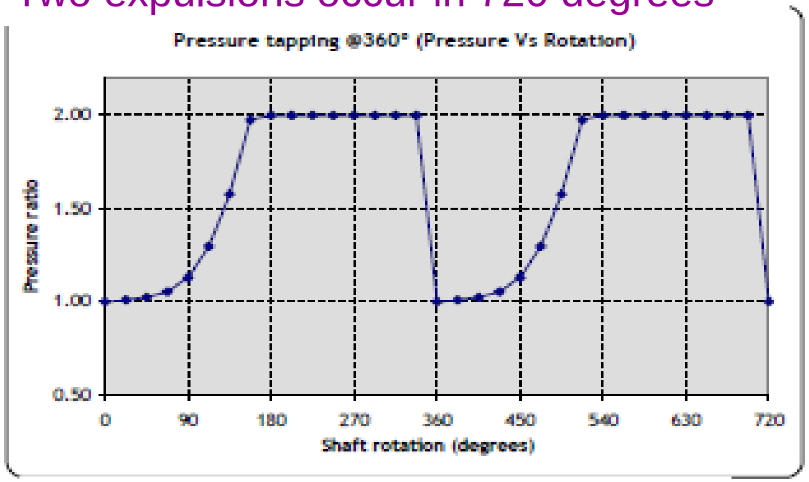
Note: There are two chambers in one swashpump.

Theoretical SwashPump PV diagram vs. Actual SwashPump PV diagram

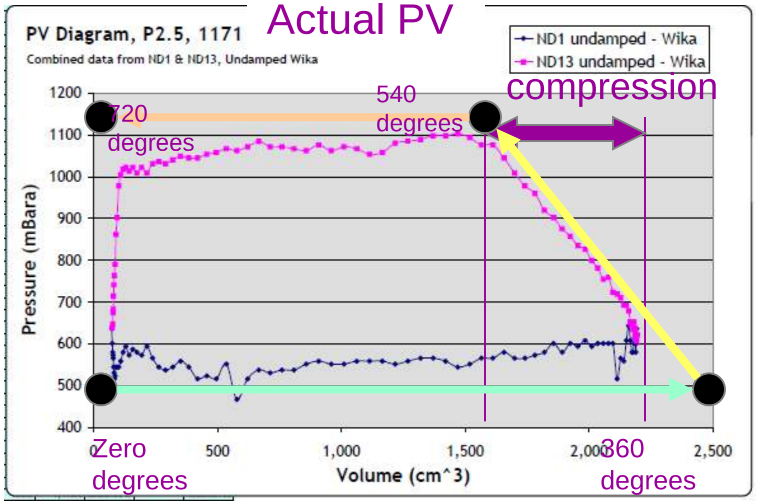
Theoretical PV



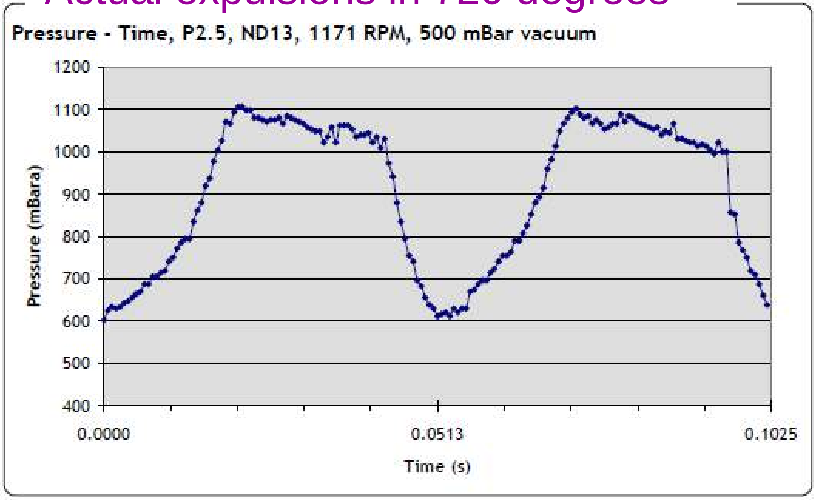
Two expulsions occur in 720 degrees



Actual PV



Actual expulsions in 720 degrees



Materials Considerations

Comparision of possible construction materials

Material	Description	Density Kg/m^3	CTE x10E-6 m/m.K	k W/m.K	E Gpa	Fy Mpa	Ni %	Cr %	Cost / Kg $	Caustic	Castability	Machinability	Heta treatment & Grinding Reqd?
Ni Resist	As previously prototyped	7400	18.7	13	150	205	20%	3%	$ 6.60	B	C	C	No
StStl AISI 420	Martinsitc Stainless steel	7800	10.3	25	200	345	0%	13%		C	C	C	Yes
StStl AISI 2205	Duplex Stainless steel	7800	13.0	14	200	450	6%	23%		A	D	D	No
High Chromium Iron	Wear resistant grade of cast iron	7700	10.0				1%	12%		D	D	C	Yes
Aluminium LM13	Cast aluminium	2700	19.0	167	73	160	2%	N/A	$ 6.00	F	B	A	No
Ni Resist Type D-5		7700	5.0			200	35%	0%	$ 10.00				
Grey cast iron		7300	11.0	52	150	200	0%	1%	$ 2.00				No
PPS	High Temp Plastic	1.5	20.0		15	120	0%	0%	$ 30.00	B	A	A	No
Titanium-6AL-4Va	High tech!	4500	9.2	6	117	760	0%	0%	$ 71.00	A			No

Density	Density	How heavy it is.
CTE	Coefficient of thermal expansion at 20 ° C	How much it expands with temperature.
k	Coefficient of thermal conductivity	How quickly it conducts heat.
E	Youngs modulas	How rigid it is.
Fy	Yield strength	How strong it is.
% Ni	Percentage of Nickel in the material	Big determinant of material cost
% Cr	Percentage of Chromium in the material	Big determinant of corrosion resistance
Caustic	Corrosion resistance to caustic cleaning solutior	Graded from A (excellent) to F (Poor)
Castability	Castability	Graded from A (excellent) to F (Poor)
Machinability	Machinability	Graded from A (excellent) to F (Poor)
Heta treatment &	Heat teatment req'd to develop full strength of the material. May not be a requirement, as stiffness is important, not strength.	