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Director of Research

SURVEILLANCE TEST OF PENGUIN MK2 MOD7 MOTOR S/N 202

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8) ABSTRACT

Surveillance test of Penguin Mk2 Mod7 rocket motor s/n 202 is described.

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SURVEILLANCE TEST OF PENGUIN MK2 MOD7 MOTOR S/N 202

1 CONTRACT

FFI (Norwegian Defence Research Establishment) has reached an agreement with the Royal Norwegian Navy Materiel Command about writing a report on the surveillance test of the Penguin Mk2 Mod7 motor.

Nammo Raufoss AS has a contract with Kongsberg Defence and Aerospace AS (KDA) on the surveillance test of one Penguin Mk2 Mod7 rocket motor.

In addition, some parallel and separate tests of the propellants are planned in Sweden. Those tests are not complete yet, and are not part of the above agreement.

2 ROCKET MOTOR DESCRIPTION

The Penguin Mk2 Mod7 rocket motor consists of a *sustainer* (forward part) and a *booster* (rear part). The metal parts are made of high strength steel. The propellants consist of a Hydroxyl Terminated PolyButadiene (HTPB) rubber (fuel) and ammonium perchlorate (oxidizer). The propellants differ in composition and burning rate.

The propellant gas from the sustainer motor is led through a central tube in the booster to its nozzle in the aft end. The propellant gas from the booster leaves the motor through six nozzles located in the aft bulkhead (end plate).

The booster propellant is cast in the motor shell with the insulation already in place. The sustainer propellant is produced in one unit that is loaded through the forward bulkhead.

Both motors are simultaneously ignited by an electric current to a Safe and Arm Device (SAD) located on the aft bulkhead. From the SAD their respective Rapid Deflagration Cord (RDC) set fire to their respective igniters. The energetic material in the booster igniter is boron-potassium-nitrate (B-KNO_3) pellets. The energetic material in the sustainer igniter is 8 % boron, 6 % tri(2)ethylhexylphosphate, 6 % vinylbutyral, and the balance is potassium perchlorate.

The energetic materials are sealed against humidity by O-rings and seals in the nozzles.

The steel is protected against corrosion by surface treatment. Where exposed to free air, the steel is in addition protected by paint. The paint also protects against scratches during handling and service.

3 HISTORY OF MOTOR WITH SERIAL NUMBER 202

The motor was produced by Raufoss AS in 1993 for US Navy via main contractors. In 1998 this motor was returned to Nammo Raufoss AS for repair/replacement of the aft fairing. After repair in January 1999, it was stored at Nammo Raufoss AS facility at Raufoss until November 2001.

Nothing is known about the history between 1993 and 1998. However, lack of handling marks indicate that the motor has been on the shelf most of the time.

4 SURVEILLANCE

All tests, except Dynamic Mechanical Analysis (DMA), have been performed by Nammo Raufoss AS. Nammo Raufoss AS subcontracted the DMA test to FFI.

The test program is visualized in the Nammo Raufoss AS report (Figure 1 – Flow Chart).

The Swedish Navy has also received some propellant parts for analysis at Celsius laboratories. This is not part of the contract, and the result is not known at the time of writing.

5 INSPECTIONS

The author inspected the first remote controlled cut in the booster motor tube at Nammo Raufoss AS on December 05, 2001.

6 CONTROL OF NAMMO RAUFOSS AS DRAFT

The author looked through the Nammo Raufoss AS final draft report at Nammo with E A Løkke and T Hjelmås on January 10, 2002. One misprint correction and a few minor changes were made to the final report.

The report gives a complete description of the test results.

7 REPORT FROM NAMMO RAUFOSS AS

The Nammo Raufoss AS report dated January 09, 2002 is prepared by E A Løkke and T Hjelmås. The Document is numbered 604550-1400, and has the same title as this report. The Nammo Raufoss AS report is enclosed in the appendix.

The author obtained a limited copyright of the Nammo Raufoss AS report.

8 COMMENTS TO THE NAMMO RAUFOSS AS REPORT

1. No external corrosion or significant scratches were found. This indicates that the motor has been on the shelf most of the time.

2. The electric resistance between various pins in the contact on the Safety and Arm Device (SAD) indicate that it is serviceable. Firing later in the surveillance program confirmed this indication.

3. Radiographic inspection by X-ray disclosed debond in a small area between the booster propellant and the middle bulkhead. Visual inspection later in the surveillance program showed that debond between insulation and steel had taken place almost around the circumference of the bulkhead. The insulation was bonded to the propellant. The insulation has double thickness in this area.

Debond is the result of longitudinal crimp and was not discovered by principally the same type of radiographic analysis in 1993, and is either a result of imperfect production or ageing.

The curing of the propellant took place at approximately 60 Centigrade. The thermal expansion coefficient of a HTPB propellant is between 1.0 exp-4 and 1.2 exp-4 per Centigrade (10 times that of steel). Temperature reduction from 60 to 21 Centigrade will shorten a complete debond booster with approximately 2 mm. The calculated average debond force on the middle bulkhead for a bonded propellant will be in the order of 0.03 MPa at 21 Centigrade. The debond force will be highest at the periphery. At –40 Centigrade, the average debond force is calculated to be in the order of 0.3 MPa.

The space between the inhibitor and the middle bulkhead is expected to be approximately 1 mm at 21 Centigrade if there is a complete debond. At –40 Centigrade the space is expected to be 2.5 mm. Boost acceleration will increase the space to some degree.

In the case the booster propellent burns through the insulation in the forward end of the bore, the thickness of the isulation will prevent ignition of booster propellant in the debond area. However, a space between the propellant insulation and the middle bulkhead may result in an increase of the temperature of the middle bulkhead during firing, the more space, the higher the temperature. At a low operational temperature the sustainer pressure is lowered and the bulkhead will probably have sufficient strength. At a high operational temperature, the space volume may be nil, therefore no extraordinary temperature increase, and the bulkhead strength will be sufficient.

4. The humidity in the booster and sustainer atmosphere is low, as expected for a propellant with this hygroscopicity. The test method will not disclose a microscopic leak.

5. Leakage tests showed that all weather seals and O-rings were intact. The test method is not accurate enough to disclose a microscopic leak.

6. The visual inspection showed that all components were in place, and there were no corrosion on the metal parts.

7. The booster igniter vented bomb firing showed significantly less time to max pressure, compared with the lot acceptance test in 1993. The reason is not known. It might be a statistical variation.

8. The sustainer igniter vented bomb firing also showed significantly less time to max pressure and in addition a higher pressure time integral compared with the lot acceptance test in 1993. The reason is not known. It might be a statistical variation alone. Ageing of the igniter is not expected.

9. The Safety and Arming Device (SAD) armed and fired properly.

10. The Sustainer Nozzle and Forward Closure O-rings show rupture strain that is less than required for new O-rings. The sustainer Nozzle O-ring also shows a remarkable high E-module. This might be the result of ageing (oxidation).

11. The sustainer propellant mechanical properties have not changed much.

The adhesion of the sustainer propellant to the insulation (rubber) has been reduced to some degree since production. The adhesion is acceptable.

The humidity in the sustainer propellant is small (0.021 % by weight).

The sustainer propellant burning rate at 21 Centigrade seems to be in the same order as when produced. The difference may be due to different test methods.

12. The booster propellant mechanical properties have not changed much.

The adhesion of the booster propellant to the inhibitor (rubber) has been reduced to some degree since production. The difference is probably due to different test methods and ageing. The adhesion is acceptable.

The humidity in the booster propellant is small (0.023 % by weight).

The booster propellant burning rate at 21 Centigrade seems to be in the same order as when produced. The difference may be due to different test methods.

13. Dynamic Mechanical Analysis (DMA) on the sustainer and booster propellants were not performed in 1993. The glass transition temperature is lower then –77 Centigrade, which is well below the minimum operational temperature.

DMA master curves for the booster and sustainer propellants are established, and may be used for comparison in future surveillance testing.

9 APPLICATION OF MK2 MOD7 AND SIMILAR ROCKET MOTORS

The Penguin Mk2 Mod7 motor is used in the helicopter version of the Penguin missile.

The Penguin Mk2 Mod6 motor is similar (shorter sustainer) and will replace the double base propellant motor in the Penguin Mk2 Mod5 ship missile.

Due to a high degree of similarity, both types of motors may enter into a future common surveillance program.

10 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the surveillance test, the Penguin Mk2 Mod7 motor:
- is safe to fire
- has high expected reliability

The debonding of the booster propellant from the middle bulkhead may (but probably not) reduce the sustainer reliability.

The degradation of some O-rings will require a revision at some later date.

Based on the test results we recommend that:
- a surveillance program for the Penguin Mk2 Mod7 and Mod6 motors should be established.
- a live missile firing register should be a part of a surveillance program.

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1. INTRODUCTION

Surveillance test of one Penguin MK2 MOD7 rocket motor has been performed. The motor was manufactured in 1993 and accordingly it had an age of 8 years at the time of the test.

The motor serial number was 202, and the lot number was RAN93L001-007.

The main activities involved in the surveillance test are shown in the Flow Chart in figure 1.

Propellant samples from both booster and sustainer propellant have been supplied to the Royal Swedish Navy for testing. More propellant samples are available for individual users tests.

This motor test is planned to be the first test in the planned Penguin MK2 MOD6&7 Motor Surveillance Program.

2. REFERENCED DOCUMENTS

604550-1300	Scope of Work, Surveillance Test of Penguin MK2 MOD7 Motor s/n 202
617556-811	Booster Igniter Specification
617489-811	Sustainer Igniter Specification
604550-816	Specification, Cable Harness/Safe and Arm Device Assy
STANAG 4506	Explosive Materials, Physical/Mechanical Properties, Uniaxial Tensile Test
STANAG 4540	Dynamic Mechanical Analysis
CPIA Publication no 21.	
FFI/NOTAT-2002/00092	Dynamic Mechanical Analysis on Booster and Sustainer Propellant in the Penguin MK2 MOD7 Missile.

2.1 Nammo Raufoss – Instructions (in Norwegian language)

604550-766	Røntgenkontroll av komplett motor.
R-039-1RL	Strekkprøving av drivstoff med INSTRON 4465 iht CPIA Publ. no 21.
R-033-1RL	Måling av peelstyrke med INSTRON 4465.
R-058-1RL	Peeltesting av drivstoff/isolasjon med MTS Alliance RT/10.
R-047-1RL	Bestemmelse av fuktighet med Metrohm 737 KF Coulometer
R-015-1RL	Brenning av strenger i Crawford bombe.

3. TEST OBJECT

The test object was a Penguin MK2 MOD7 rocket motor with the following data:

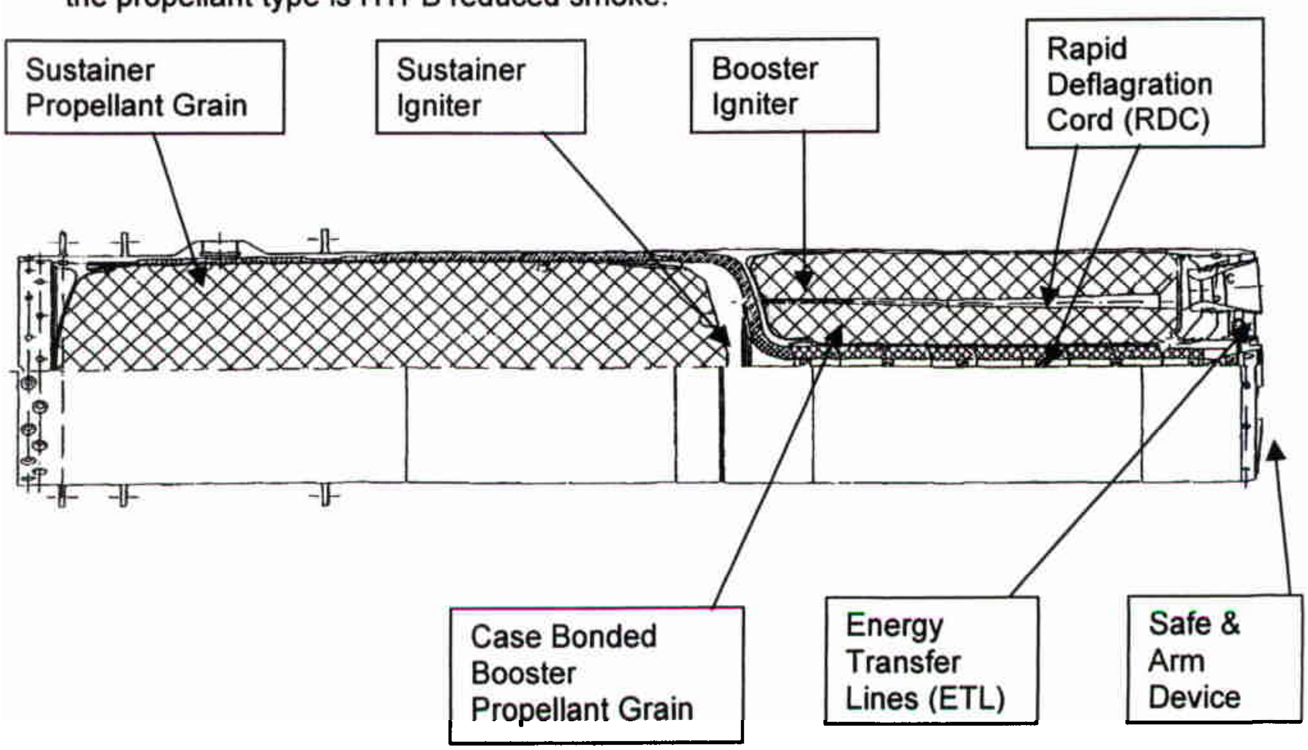
Serial number : 202
Lot number : RAN93L001-007
Age : 8 years

The motor consisted of the following major components:

COMPONENT	DRAWING NO.	SERIALNO.	LOT NO.
Motor Assembly	604550-000-T	202	RAN93L001-007
Case, Motor, Insulated	613800-000-G	1-133	-
Propellant, Grain Booster	605207-000-G	1-133	PA01-007
Propellant, Grain Sustainer	605165-000-G	083/93	PA02-008
Igniter Assembly, Sustainer	617489-000-E	032/93	1/93 (s/n 1 – 65)
Igniter Assembly, Booster	617556-000-H	002/93	01-RA-93
Cable Harness/SAD Assy	605293-000-J	0263/93	-

The motor was in operation with US-Navy from 1993 to 1998. In 1998 the motor was returned to Raufoss for replacement of the End Plate (External rear cover). The End Plate was replaced in January 1999. This work also included Leakage Test and SAD Electrical Testing. From January 1999 to August 2001 the motor has been stored at Nammo Raufoss packed in its shipping container.

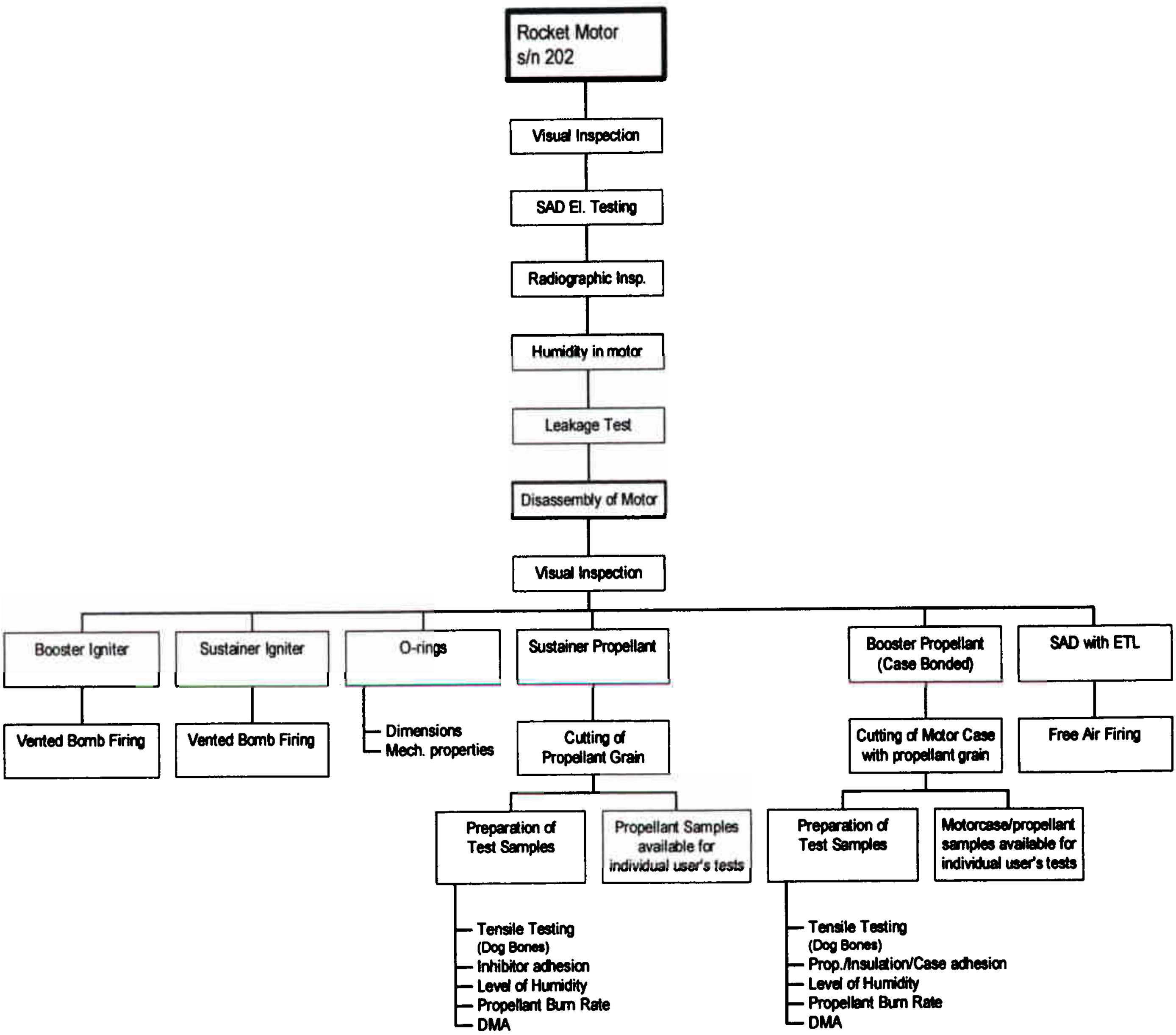
The figure below shows the major parts and components of the MK2 MOD7 rocket motor. The MK2 MOD6 motor has a sustainer propellant grain that is 50 mm shorter than the MOD7, otherwise the internal design, components and materials are identical. The sustainer propellant grain is cartridge loaded, and the propellant type is HTPB reduced smoke.
The booster propellant grain has a rod and shell configuration and is case bonded, and the propellant type is HTPB reduced smoke.



4. TEST PROGRAM

The test and inspections as shown in the flow chart below were performed on the motors:

Figure 1 – Flow Chart



5. TEST RESULTS

5.1 Visual Inspection

The motor were unpacked and visually inspected. The external condition of the motor was good, and no corrosion was observed.

5.2 SAD Electrical Resistance

Electrical resistance in the SAD circuits were measured. The results are compared with the measurements performed in 1993 and 1999 in the table below.

No.	Safe/Arm	Position (Pin to Pin)	Requirement (604550-816)	1993 (Ω)	1999 (Ω)	2001 (Ω)	Circuit
1	Arm	1-2	1.2 – 1.7 Ω	1.26	1.23	1.21	EED1
2	Arm	3-4	1.2 – 1.7 Ω	1.27	1.24	1.22	EED2
3	Safe	6-7	27 –30 Ω	29.7	29.1	29.8	Solenoid
4	Safe	13-9	<0.7 Ω	0.46	0.40	0.41	Monitor
5	Arm	13-9	>300 Ω	ok	ok	ok	Monitor
6	Arm	13-8	<0.7 Ω	0.46	0.41	0.41	Monitor
7	Safe	13-8	>300 Ω	ok	ok	ok	Monitor

The small variation in the results confirms that the SAD still is in good condition, and no ageing effects can be seen. All results are within specification limits.

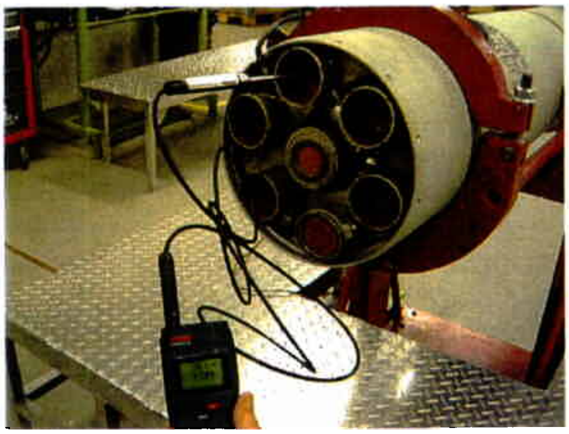
5.3 Radiographic Inspection

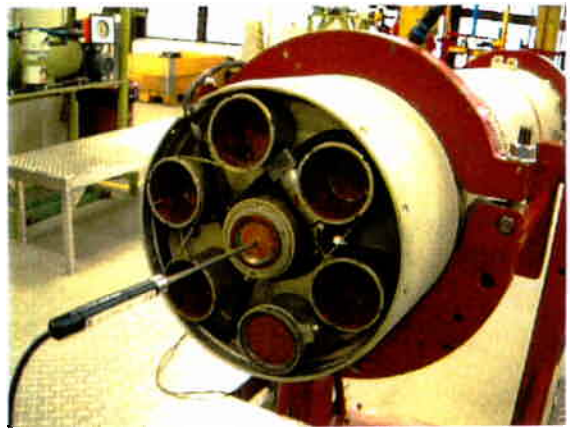
The motor was radiographic inspected in two planes in accordance with instruction 604550-766. The results were compared with the results from the radiographic inspection when manufactured in 1993.
A small debond was discovered between the booster insulation and steel bulkhead. The debond was only visible in one plane with the same rotational orientation as the launch lug. (See para 5.6.6.1) The debond was not visible on the x-ray pictures from 1993. Otherwise no significant changes or ageing effects were observed.

5.4 Humidity in Motor

Humidity of the atmosphere in both the booster and sustainer motor was measured. The measurements were performed by entering into the motor through the nozzle weather seals by a long thin probe with 5 mm diameter. The weather seal consist of a thin glass-phenolic disc with silicone rubber inside. A small hole was drilled through the glass-phenolic disc and the probe was inserted through the silicone rubber and into the motor chamber. Accordingly the silicone rubber ensured sufficient sealing against the probe to avoid exchange of internal/external atmosphere.

The following pictures show how the measurements was performed:





Results:

	Booster Chamber	Sustainer Chamber	Test Facility
Relative Humidity (%)	26,0	22,9	34,6
Temperature (^0C)	23,0	24,3	23,7

The instrument used was: HygroPalm with Rotronic HygroClip digital probe.

The measured relative humidity and temperature data pairs were converted into absolute humidity (i.e. concentration) using a standard humidity table. The absolute humidity was approximately 4.5 grams of water per kg dry air inside the booster chamber and approximately 4.3 grams of water per kg dry air inside the sustainer chamber.

These results are as expected.

The Penguin MK2 Mod7 motors are assembled in a facility where the maximum allowed humidity is 7 grams of water per kg dry air, meaning that the humidity level can vary from 1 to 7 grams of water depending of the outside climatic conditions. A humidity level of 4-5 grams is quite usual for times of the year. The air in the assembly room will then be trapped inside the free volume of the motor chambers when the motor is assembled. Leakage test to check motor seals introduces air from the outside atmosphere in the assembly room. The motor had also been leakage tested in January 1999 after the End Plate was replaced. This leakage test introduced new air from inside the test facility.

The cast propellant surfaces of the propellant grains consist of a polymer-rich layer 0.5-1mm in depth. The HTPB polymer is not very hygroscopic (water attracting) and thus protects the more hygroscopic constituents of the propellant from water influence. The migration of water into the propellant is also a slow process, and air with some humidity trapped inside the motor chambers will not affect the propellant properties drastically as long as the seals are intact protecting from further water coming into the motor chambers.

The following leakage test and measurements of water content in the booster and sustainer propellants (approximately 0.02wt% water) showed that the seals were intact and that the bulk of the propellant grains had not been subjected to moist conditions.

5.5 Leakage Test

Prior to leakage test both holes in weather seals from humidity measurements were sealed with epoxy adhesive.
Then the motor was pressurised with dry air to 0,08 MPa, and no pressure drop were recorded for 5 minutes.
Accordingly all motor seals are intact and able to protect the internal motor components from humidity and external atmosphere.

5.6 Disassembly and Visual Inspection

The motor was disassembled and components visually inspected, no irregularities were observed. The following pictures show motor components during and after disassembly:

Motor Aft End

Booster Nozzles

Booster Propellant

Sustainer Propellant

5.6.1 Booster Igniter – Vented Bomb Firing

The booster igniter was assembled into a vented bomb and static fired in accordance with booster igniter lot acceptance test. The results are compared with the results from LAT in 1993 in the table below:

Booster Igniter, Lot: 01-RA-93

	2001	LAT 1993		Requirement (617556-811)
	s/n 002/93	020/93	050/93	
Max. Pressure, (MPa)	0,84	0,79	0.83	>0,40
Time to Max. Pressure, (ms)	25	33	33	< 45
Pressure-Time Integral 10–10, (MPa*s)	0,0119	0,0112	0,0114	N/A

The pressure vs. time curves are enclosed in appendix A.

Maximum pressure is unchanged, and the pressure vs time curves shown in appendix A are very similar.
Time to max pressure has decreased by 24 %. From the curves in appendix A, it can be seen that this reduction is mainly caused by reduced time for transfer of ignition signal from the RDC (Rapid Deflagration Cord) to the $BKNO_3$ – Pellets. The reason for this is not trivial but can be explained by variation in distance between the RDC and $BKNO_3$ - pellets in the igniter. A statistical variation is expected even though the two firings from 1993 are identical.

The results confirm that the booster igniter performs acceptable and well within specification limits.

5.6.2 Sustainer Igniter – Vented Bomb Firing

The sustainer igniter was assembled into a vented bomb and static fired in accordance with sustainer igniter lot acceptance test. The results are compared with the results from LAT in 1993 in the table below:

Sustainer Igniter, Lot 1/93 (s/n 1 – 65)

	2001	LAT 1993		Requirement (617489-811)
	s/n 032/93	033/93	0036/93	
Max. Pressure, (MPa)	5,07	3,68	3,96	>3
Time to Max. Pressure, (ms)	22	34	29	<60
Pressure-Time Integral 10–10, (MPa*s)	0,2104	0,1561	0,1331	N/A

The pressure vs time curves are enclosed in appendix A.

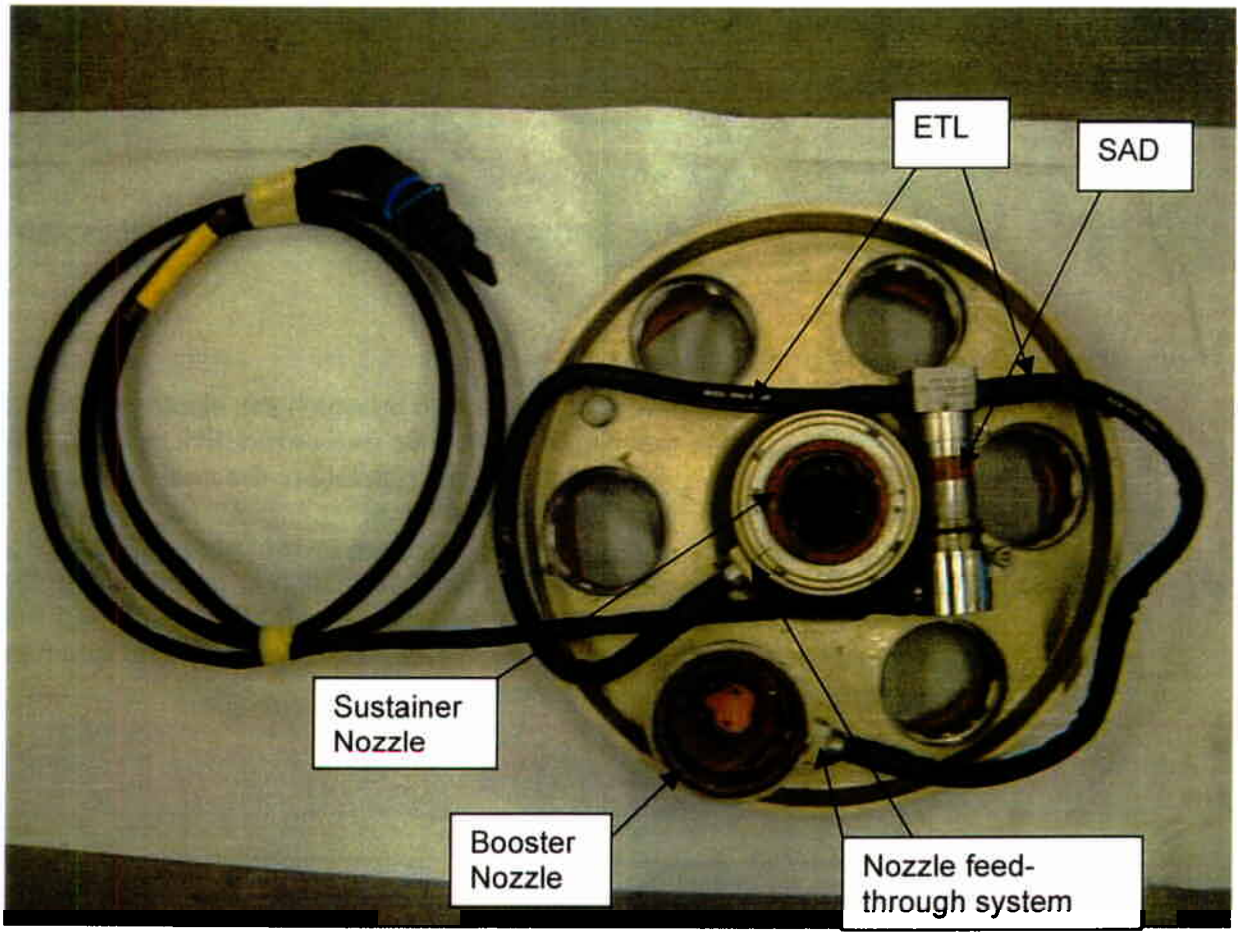
The shape of the pressure curves for all igniters is similar.
The two LAT (Lot Acceptance Test) igniters have different pressure level and time to max pressure, indicating a statistical variation from igniter to igniter. The igniter pyrotechnic material is based on Potassium Perchlorate, and is manually applied to an

igniter support made of perforated aluminium. The igniter from motor s/n 202 have a higher presure level and a shorter time to max pressure. Also the pressure-time integral is higher. A portion of this can be explained by normal statistical variation, but the result indicates a slight ageing effect.

The results show that the sustainer igniter performs acceptable and well within specification limits.

5.6.3 SAD with ETL – Free Air Firing

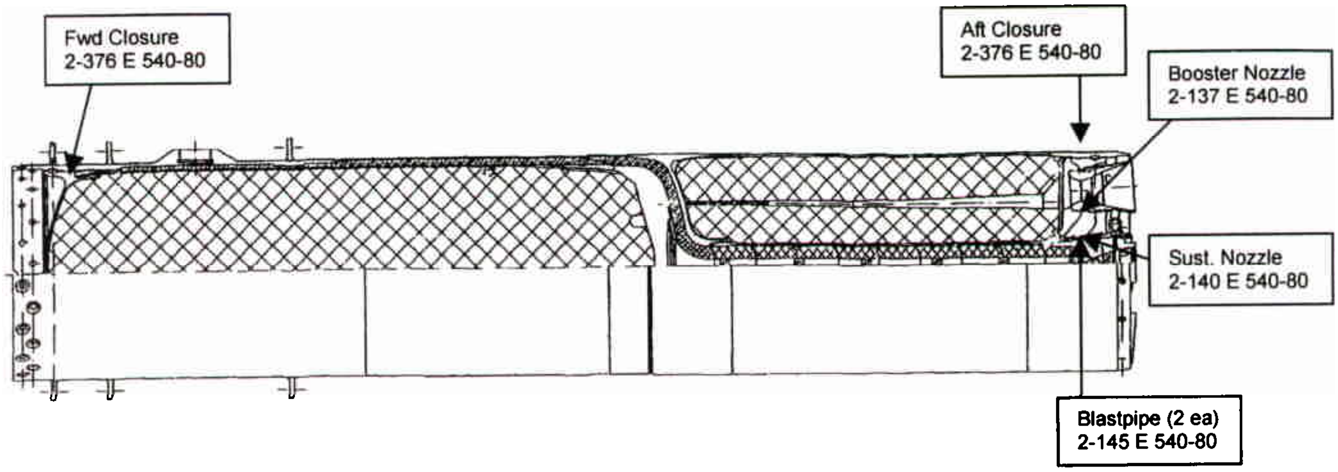
Disassembled SAD with both ETL's (Energy Transfer Lines) assembled including nozzle feed-through system, was fired in free air. All components are shown in the picture below:



The SAD was armed, and fired. Video recording during firing and visual inspection after firing verified that transfer of the pyrotechnic signal was satisfactory. Arming time was 15,5 ms.
This accordingly confirms acceptable SAD performance and transfer of pyrotechnic signal to both igniters.

5.6.4 O-ring Testing

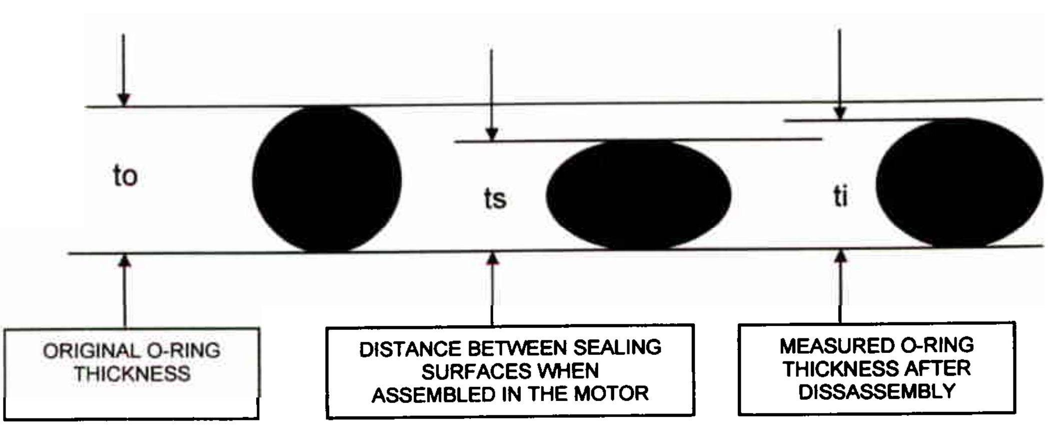
The following o-rings from motor no 202 as shown in the figure below, have been inspected and tested:



All o-rings are made from an EPDM rubber compound in accordance with Parker's compound no E 540-80.

5.6.4.1 Compression Set

Compression set is the percent of deflection by which the elastomer fails to recover after a fixed time under specified squeeze. So expressed, 0% indicates no relaxation has occurred whereas 100% indicates total relaxation; the seal just contacts mating surfaces against which it no longer exerts force.
An o-ring with high compression set will continue to seal provided temperature and system pressure remain steady and there is no motion or deflections of the sealing surfaces. Accordingly the compression set must never become so high that the o-ring cannot compensate for thermal expansion effects, movement and structural deflections caused by rocket motor pressurisation.



Compression set can be calculated as follows:

Compression set = $(t_0 - t_i) / (t_0 - t_s) \times 100$

Where: t_0 = original o-ring thickness
t_i = measured o-ring thickness after disassembly
t_s = distance between sealing surfaces when assembled in the motor
(As shown in the figure above)

The following compression set values have been calculated after measurement performed on o-rings from motor no 202:

O-ring	t_0 (mm)	t_i (mm)	t_s (mm)	Compression Set (%)
Booster Nozzles, 2-137	2,62	2,53	2,13	18
Sustainer Nozzle, 2-140	2,62	2,58	2,13	8
Aft Closure/Blastpipe, 2-145	2,62	2,53	2,14	18
Aft Closure/Sustainer N, 2-145	2,62	2,59	2,18	7
Aft Closure, 2-376	5,30	5,0	4,34	31
Fwd Closure, 2-376	5,30	4,95	4,34	36

All values of t_i are measured immediately after motor disassembly and are average values of 3 to 5 measurements on each o-ring.

The calculated compression set values for the large o-rings (Aft and Fwd Closure) are fairly high, and accordingly indicates that some relaxation has occurred.

5.6.4.2 Mechanical Testing

The o-rings from motor s/n 202 have been tested in a tensile test machine at room temperature. Hardness has been measured in a Bareiss hardness measurement equipment, and the values are given in shore A.

The results are summarised in the table below:

O - Ring	Rupture Stress (MPa)	Strain (%)	E-Module (MPa)	Hardness (Shore A)
Booster Nozzles:	16,7	261	7,3	68
Sustainer Nozzle:	18,8	66	32,6	82
Aft Closure/Blastpipe:	21	315	7,5	67
Aft Closure:	15,2	226	7,03	72
Fwd Closure:	15,4	132	6,75	72
Nominal value new o-rings, Parker compoumd E 540-80:	> 13,0	> 150	> 5,0	80 ± 5

The E-module and hardness measurements are somewhat uncertain due to the test method, but in general the results show that the o-rings from motor s/n 202 have acceptable mechanical properties.
Some ageing effects can be seen on the o-ring from the sustainer nozzle. The results for this o-ring differ from the other o-rings. Strain is lower, rupture stress, E-Module and Hardness is higher. However the compression set value calculated in para 5.6.4.1 is very low for this o-ring, indicating all together acceptable sealing properties.

5.6.5 Sustainer Propellant

The disassembled sustainer propellant grain was splitted into 4 parts as shown in figure 4.6.6 below.

Part no 2 was used by NA RA in the tests described below.

Part no 3 was shipped to the Royal Swedish Navy for testing.

Part no 1 and 4 are available for individual user's tests. Each part is packed and sealed against humidity and atmosphere by means of welded barrier bags. If necessary the parts can be splitted in two halves giving a total of 4 available samples.

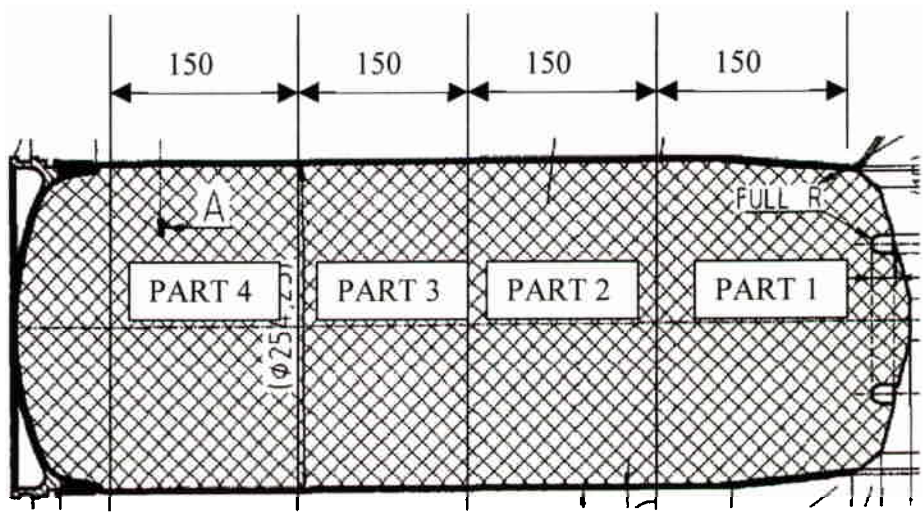


***Figure 5.6.5**: Splitting pattern of sustainer propellant grain for testing.*

5.6.5.1 Tensile Testing

Tensile testing of propellant was performed according to CPIA Publication no. 21 (laboratory routine no. R-039-1RL).

Results were also calculated according to STANAG 4506.

Test specimens were cut out from propellant part no 2 in the lengthwise direction of the motor.

Cross head speed was 50 mm/min and temperature –40, +21, and 63°C. At each temperature 5 specimens were tested.

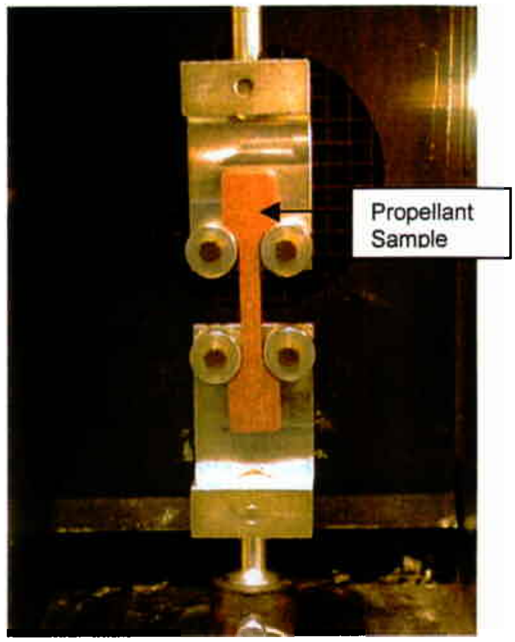


Figure 5.6.5.1: Instron 4465 Tensile Test Machine

The average results of 5 specimens are shown in the table below.

Sustainer propellant mechanical properties:

	Req.	S/N 202, CPIA no. 21	S/N 202, STANAG 4506	Production control in 1993 (CPIA no. 21)
21°C				
Max. stress, MPa	min. 0,75	1,23	1,22	1,19
Rupture stress, MPa		1,14	1,18	1,15
Strain at max., %	min. 15	26,6	24,6	27,6
Strain at rupture, %		31,0	28,5	30,7
Modulus, MPa	min. 4,50	11,27	11,25	9,10
-40°C				
Max. stress, MPa		2,91	2,93	3,21
Rupture stress, MPa		2,69	2,70	3,01
Strain at max., %		35,3	34,7	38,6
Strain at rupture, %		45,3	44,6	45,9
Modulus, MPa		52,53	53,18	50,4
63°C				
Max. stress, MPa		0,90	0,89	0,89
Rupture stress, MPa		0,83	0,83	0,84
Strain at max., %		19,8	18,6	22,3
Strain at rupture, %		24,1	22,9	26,2
Modulus, MPa		8,67	8,66	7,64

Mechanical properties of the S/N 202 sustainer are almost unchanged compared to the production control samples performed in 1993. Strength and elongation is unchanged

and modulus has increased slightly. The same effects are seen at all test temperatures except a slight drop in strength at –40°C.
The results confirm that the sustainer propellant mechanical properties can be considered unchanged since the propellant was manufactured in 1993.

All data are well within required properties of production control samples.

5.6.5.2 Adhesion Propellant Grain/Inhibitor Boot

Bond properties were tested by 90° peel test according to CPIA Publication no. 21 (laboratory routines no. R-033-1RL and R-058-1RL). Cross head speed was 25 mm/min and temperature 21°C.

The sustainer grain samples were cut lengthwise from propellant part 2, and 2 samples were tested.

Peel strength (g/cm) propellant-inhibitor of sustainer motor at 21 C. (Average of two samples):

	S/N 202	Failure mode	Production control in 1993
Sustainer	570,8	BDF	878,6

BDF = failure in interface between bondliner and propellant with residual color of propellant on bondliner.

Production control peel samples are done by preparing a sheet of inhibitor the same way and at the same time as the motor is being processed. The propellant is then cast on top of the sheet in a pan.

The different result compared to the production control in 1993 can be explained by difference in test samples. The peel test samples taken from the sustainer grain in motor s/n 202 had a bondline with a diameter of ø260 while the production sample from 1993 had a plane bondline.

Picture showing peel test samples from sustainer grain of motor s/n 202. Samples are taken in the lengthwise direction of motor with a bondline diameter of ø260mm.

5.6.5.3 Humidity Content in Propellant

Moisture in propellant was determined by coulometric Karl Fischer analysis (laboratory routine no. R-047-1RL).

Samples were cut from part 2 of sustainer propellant grain. The samples were grated and immediately analyzed.

Sustainer: 0,021 weight%

The moisture level of the sustainer propellants is low and within the requirements of the propellant ingredients used. The moisture levels indicate that the motor grains have not been subjected to moist conditions, and thus that motor seals have functioned properly.

5.6.5.4 Propellant Burn Rate

Propellant burn rate was determined by strand burning (laboratory routine no. R-015-1RL). Temperature was 21°C and the pressure ranges 3 – 11 MPa.

Burn rate data at 21°C of sustainer grain.

	Req. for 2" model motor	**S/N 202 (strand burning)**	**Production control in 1993 (2" model motors)**
Burn rate @ 5 MPa (mm/s)	6,2 – 6,9	6,11	6,52
Pressure exp.		0,48	0,45
Pressure range (MPa)		3-11	5-14

The propellant burn rates of S/N 202 were characterized by strand burning while production control was measured by 2" model motors. Different test methods for ballistic properties can give different results.

The correlation between strand burning and 2" model motors is not fully established. A difference in burn rate up to 5% in either direction can be measured.

Taking into account the uncertainties, the results are within expected range.

5.6.6 Booster Propellant Grain

The outer case bonded booster propellant grain (shell part) was splitted into 3 parts as shown in figure 5.6.6 below.

Part no 1A and 3 were used by NA RA in the tests described in paragraphs below.

Part no 2 was shipped to the Royal Swedish Navy for testing.

Part no 1 will be available for individual user's tests. The sample are packed and sealed against humidity and atmosphere by means of welded barrier bags and stored at Nammo Raufoss.

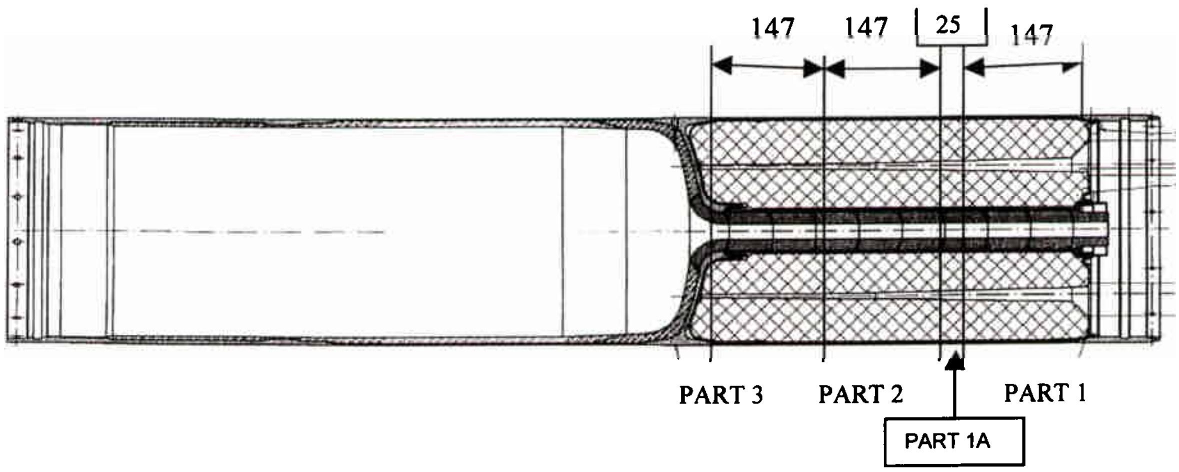
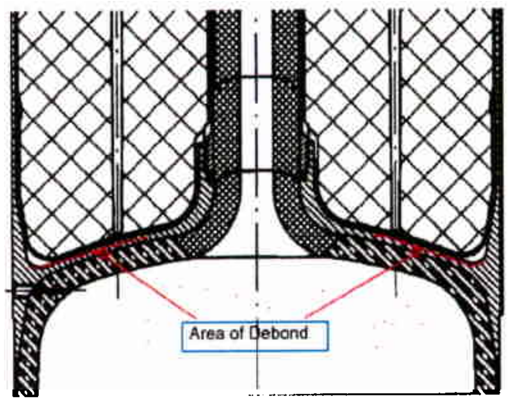


***Figure 5.6.6**: Splitting pattern of booster motor for testing.*

5.6.6.1 Visual Inspection

After cutting and removal of the steel/propellant parts from the booster motor the remaining parts of the booster motor were visually inspected.
A debond between the insulation and steel was observed on the booster side of the bulkhead, as discovered during the radiographic inspection mentioned in para 5.3. The debond is shown by the figure below and extended more or less all the way around the circumference of the bulkhead.



The preformed insulation part in the booster bulkhead area consists of a propellant stress relief system where there are two layers of insulation separated by a thin separator sheet. The upper layer is bonded to the propellant and the lower layer is bonded to the steel bulkhead. This system allows the propellant to shrink at low temperatures and to expand at high temperatures without creating high stresses in the propellant or its bondline to other materials. Since this stress-relief insulation part is preformed and precured prior to assembly into the motor a different primer/adhesive system is used in this area compared to remaining part of the motor chamber where the insulation is cured to the steel case and blastpipe. However both bonding systems have previously been tested thoroughly and demonstrated good results. Test results in para 5.6.6.3 show very good adhesion between insulation and steel on the cylindrical part of the motor case.

Debonding between insulation and steel case in this area will not influence motor performance, since the insulation material (EPDM with Kevlar fibres) is relatively thick (two layers) and there is very little gas flow in this area. Previous inspections of fired motors show no or very little erosion and degradation of the insulation in this area.

5.6.6.2 Tensile Testing

Tensile testing of propellant was performed according to CPIA Publication no. 21 (laboratory routine no. R-039-1RL).

Results were also calculated according to STANAG 4506.

Test specimens were cut out from propellant part no 3 in the lengthwise direction of the motor.

Cross head speed was 50 mm/min and temperature –40, +21, and 63°C. At each temperature 5 specimens were tested.

Booster propellant mechanical properties, (average of 5 samples):

	Req.	CPIA no. 21	STANAG 4506	Production control in 1993 (CPIA no. 21)
21°C				
Max. stress, MPa	min. 0,5	1,26	1,24	1,00
Rupture stress, MPa		1,23	1,21	0,99
Strain at max., %	min. 19	31,3	27,4	33,2
Strain at rupture, %		32,1	28,3	34,8
Modulus, MPa	min. 3,0	6,88	6,84	4,83
-40°C				
Max. stress, MPa		3,01	2,96	2,55
Rupture stress, MPa		2,83	2,78	2,36
Strain at max., %		30,3	30,1	29,7
Strain at rupture, %		35,8	35,6	37,6
Modulus, MPa		31,13	30,80	21,6
63°C				
Max. stress, MPa		1,02	1,01	0,82
Rupture stress, MPa		1,01	1,00	0,81
Strain at max., %		29,4	25,3	32,2
Strain at rupture, %		29,9	25,7	32,6
Modulus, MPa		5,43	5,40	3,69

The mechanical properties above shows that the booster propellant of S/N 202 has increased strength, slightly decreased elongation and increased modulus compared to production control data. These are typical aging properties of HTPB-propellant. The same effects are seen at all test temperatures.

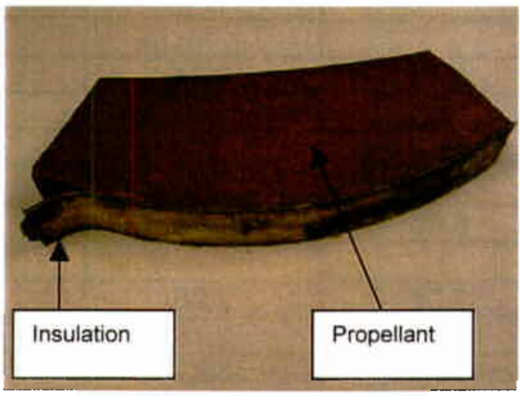
All data are well within required properties of production control samples.

5.6.6.3 Adhesion Propellant Grain/Insulation/Motor case

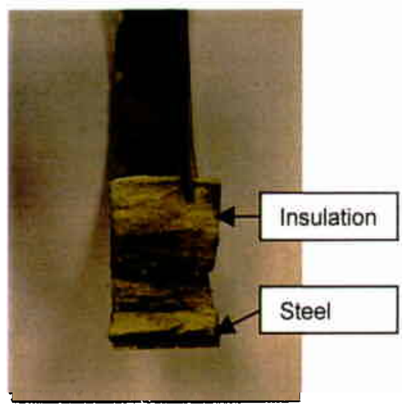
Bond properties were tested by 90° peel test according to CPIA Publication no. 21 (laboratory routines no. R-033-1RL and R-058-1RL). Cross head speed was 25 mm/min and temperature 21°C

For the booster grain a ring of 25 mm width was cut from the motor (Part no 1A, figure 5.6.6). The ring was cut in four segments. Two of the segments were used for testing of insulation to propellant bond strength and the other two for testing of insulation to steel.

On the insulation to propellant samples the insulation was separated from the steel case by using a 0,2 mm piano wire. A steel edge was pressed into the inhibitor by the dissection operation and the separation was time-consuming as this edge had to be removed ahead of separation. The insulation to steel samples were prepared by cutting the propellant with a cheese knife at the insulation/propellant interface.



Peel Test Sample
Propellant/Insulation



Peel Test Sample
Insulation/Steel

Table 3. Peel strength (g/cm) results of booster motor:

	S/N 202	Failure mode	Production control in 1993
21°C			
Propellant/Insulation	496,4	BDF [1)]	746,8
Insulation/Steel case	2700	Insulation	-

[1)] BDF = failure in interface between bondliner and propellant with residual color of propellant on bondliner.

Some propellant samples had to be rejected due to partly damaged bondline during preparation of the samples. (Cutting and separation from steel). Accordingly the result above is from one sample only.

The production control peel samples are performed by preparing a sheet of insulation the same way and at the same time as the motor is being processed. The propellant is then cast on top of the sheet in a pan. The insulation sheet used for this test is 2 mm thick, which is approximately twice as thick as the insulation on the sample from motor 202. This thicker insulation can explain the higher peel results obtained in the production control in 1993.

Testing of bond strength of the insulation to steel show very good results. The peel strength of the bondline was higher than that of the insulation material itself.

5.6.6.4 Humidity Content in Propellant

Moisture in propellant was determined by coulometric Karl Fischer analysis (laboratory routine no. R-047-1RL).

Samples were cut from propellant sample no 3. The samples were grated and immediately analyzed.

Results: 0,023 weight%

The moisture level of the booster propellant of S/N 202 is low and within the requirements of the propellant ingredients used. The moisture levels indicate that the motor grains have not been subjected to moist conditions, and thus that motor seals have functioned properly.

5.6.6.5 Propellant Burn Rate

Propellant burn rate was determined by strand burning (laboratory routine no. R-015-1RL). Temperature was 21°C and the pressure range 4 - 14 MPa.

Burn rate data at 21°C for booster grain.

	Req. for 2" model motor	S/N 202 (strand burning)	Production control in 1993 (2" model motors)
Booster			
Burn rate @ 9 MPa (mm/s)	19,6-22,2	22,38	20,57
Pressure exp.		0,36	0,26
Pressure range (MPa)		4-14	5-9

The booster propellant burn rates of S/N 202 were characterized by strand burning while production control was measured by 2" model motors. Different test methods for ballistic properties can give different results.

The correlation between strand burning and 2" model motors is not fully established. A difference in burn rate up to 5% in either direction can be measured.

For the booster propellant it should also be noted that the production control data are from a narrower pressure range and that this entails a lower pressure exponent and burn rate. Using the same pressure range for the strand burn data gives burn rate 21,87 mm/s and pressure exponent 0,34.

Taking into account the uncertainties, the results are within expected range, both with regards to production control data and requirements.

5.6.7 Dynamic Mechanical Analysis (DMA)

The test was performed on both booster and sustainer propellant samples from motor 202 by FFI (Norwegian Defence Research Establishment). The detailed test results are described in FFI Report: FFI/NOTAT-2002/00092.

This test has not previously been performed on propellant from the Penguin MK2 MOD6 or MOD7 rocket motor. Accordingly no reference exists, but the results shown here and as contained in the FFI Report will establish a basis for future motor surveillance testing.

The glass transition temperature was determined for both propellants. A master curve was also generated for each propellant in the desired temperature range (-70 to 65°C).

The tests have been performed according to STANAG 4540 "Procedures for Dynamic Mechanical Analysis (DMA) and Determination of Glass Transition Temperature". The instrument used was a DMA 2980 from TA Instrument, and the specimens were fixed in the instrument by a "Dual-cantilever" clamp. The instrument was calibrated according to the manufacturer's recommendations. The specimen dimensions were measured at room temperature with a slide calliper, and with an accuracy of one percent of the smallest dimension. The procedure used for determining the glass transition temperatures was different from the procedure used to produce the data needed for the generation of the master curves for the two propellants. To get the best resolution for the Tg, we only used one time-cycle or frequency in the procedure for determining the Tg. One measuring point each 2 second, with 1°C/min heat rate, gave a resolution of 1/30°C. For generating the master curve we have to use a multi-frequency method and the temperature has to incremented in step (here 2°C and 5°C step), resulting in a resolution 60 times smaller.

5.6.7.1 Glass Transition Temperature

Dynamic Mechanical Analysis is the preferred method for determination of the Glass Transition Temperature (Tg) of solid propellants and other explosive materials. This is due to the fact that Tg represents the temperature at which a mechanical transition occurs in the material and therefore should be measured by a mechanical method. In the analysis the material is subjected to a cyclic, usually sinusoidal, deformation with the stress and strain being recorded continuously. The stress and strain information is analysed to produce the storage moduli (E') and the loss moduli (E"). It is customary to measure these parameters as a function of temperature and often as a function of frequency (time) of deformation. Tg is the temperature at which main molecular motions ceases, and the value of Tg is obtained from the peak in the loss modulus versus temperature curve. Tg is frequency and amplitude dependant and it is important that these two conditions are stated in the test report. The ratio between frequency and amplitude is proportional to strain rate.

STANAG 4540 requires the results to be reported in a standard exchange format. This is a test report sheet with curves of storage moduli and loss moduli versus temperature, tables with storage moduli and loss moduli at 13 different temperatures and the Tg. Test report sheets for one specimen from each propellant are given in Appendix C

The result from the instrument is a plot with curves of Storage Modulus (E'), Loss Modulus (E") versus temperature. One plot for one specimen from each propellant is given in Appendix C. Tg for the specimens tested according to the test method for determination of Tg is given in Table 5.6.7.1

Specimen no.	Tg Booster Propellant (°C)	Tg Sustainer Propellant (°C)
1	-78.29	-78.01
2	-79.36	-78.12
3	-79.02	-77.51
4	-79.51	NA
Average	(79.0 ± 0.7)	(-77.9 ± 0.5)

Table 5.6.7.1 Tg (in °C) for the Booster and Sustainer Propellant Penguin Motor Series 202. The average value is given with its 95% confidence interval

The test results are as expected, and confirm that the glass transition temperature for both propellants is well below the minimum operational temperature limit of the rocket motor.

5.6.7.2 Master curves

The behaviour of viscoelastic materials during deformation is both temperature and time (frequency) dependent. The deformation or strain exhibit by a polymer subjected to a constant load will increase over a period of time. This is because the material undergoes molecular rearrangement in an attempt to minimize the localized stresses. To evaluate material performance for a specific application the material has to be tested under the actual temperature and time conditions the material will see in the application. This could result in an extremely long experiment.

If the time-dependant stress-strain relation of a material can be described by linear differential equations with constant coefficients, the material is defined as linear viscoelastic. Tests of propellant similar to the Penguin propellant have shown that they can be regarded as linear viscoelastic materials. The time-temperature superposition (TTS) method is used to translate the data obtained from dynamic mechanical multi-frequency tests to viscoelastic properties (constants).

The underlying bases for the TTS are that the processes involved in molecular relaxation or rearrangements in viscoelastic materials occur at the accelerated rates at higher temperatures and that there is a direct equivalence between time (or frequency of the measurement) and temperature. Hence, the time over which these processes occur can be reduced by conducting the measurement at elevated temperatures and transposing (shifting) the resultant data to lower temperatures. Viscoelastic data can be collected by performing static measurements under isothermal conditions (e.g. creep, stress-relaxations or simple tensile tests), or by performing frequency-multiplexing experiments where a material is analysed at a series of frequencies. Each isothermal measurement can be represented as curve in a log-log plot of i.e. modulus versus time (frequency). By selecting a reference curve (temperature) and shifting the other curves with respect to time (or frequency), a "master curve" can be generated. This "master curve" can be used to describe the material property at a specified end-use temperature over a broad time scale. The degree of time shift required to shift each set of data to the reference can be mathematically described with respect to the temperature. The most commonly used model is the Williams-Landel-Ferry (WLF) (0.1) equation.

$$\log a_T = \frac{-C_1(T - T_0)}{C_2 + (T - T_0)} \qquad (0.1)$$

In the equation T_0 is the reference temperature, T is the measurement temperature and a_T is the shift factor. C_1 and C_2 are constants. If the experimentally determined shift factors are well fitted to any of the mathematically models the master curve can be shifted to any desired temperature, and thereby the describe the material far beyond the experiment time and temperature limits.

The result from the instrument is a plot with curves of Storage Modulus (E'), Loss Modulus (E") versus temperature with one curve for each frequency in the frequency table. One plot for each propellant is given in Appendix D, of master curve and shift factors versus temperature. In the shift factors versus temperature plot there is also a curve of the WLF fit to the shift factors. The C1 and C2 constant, together with reference temperature used and the resulting standard error are given in Table 5.6.7.2. In the master curve plot the axes are not set correct by the software program. The X-axis should be Log(Frequency · a_T). The left and the right Y-axis should be Log(E'·T_0/T) and Log(E"·T_0/T), respectively.

WLF Parameter	Booster Propellant	Sustainer Propellant
C1	9.568	9.187
C2	207.4	201.0
Reference temp. (^{0}C)	20.3	20.3
Standard Error	21.86	9.233

Table 5.6.7.2 WLF parameters for the Booster and Sustainer Propellant Penguin Motor Series 202.

The results are acceptable, and establish a reference for future surveillance testing.

6. DISCUSSION OF RESULTS

6.1 Radiographic Inspection

During radiographic inspection of the motor a small debond was discovered in the booster motor, between the EPDM/Kevlar insulation and the steel bulkhead separating the two motor chambers. The debond was not visual on the x-ray from 1993.

The debond was confirmed by visual inspection after disassembly and cutting of steel/propellant samples from the booster motor as described in para 5.6.6.1. The debond will not influence motor performance since the insulation is relatively thick, and there is very little gas flow to erode or degrade the insulation in this area. The bonding between the insulation and steel in other parts of the motor were tested in para 5.6.6.3 and evaluated to be very good. However the observation indicate that this area should be addressed in future surveillance tests.

6.2 Humidity in Motor

Since HTPB composite propellant is vulnerable to moisture, humidity level in the motor and moisture level in the propellant are important parameters to be tested. The test results show low and acceptable levels in both chambers and in both propellant. Accordingly the results confirm that the motor seals have performed properly.

6.3 Igniter Firings

Both booster and sustainer igniter were fired in vented bombs and the results were compared with the results from Lot Acceptance Test (LAT) firings of the same igniter lots in 1993. The results show that both igniters still perform well inside requirements. However both igniters form motor 202 perform slightly different than the corresponding LAT tests. For the booster this can be explained by statistical variation, but for the sustainer the results indicate a slight ageing effect.

6.4 O-Rings

Compression set has been calculated from measured o-ring dimensions. The results show that the two largest o-rings (Aft and Fwd Closure) have fairly high compression set. However due to very narrow dimensional tolerances on the sealing surfaces of motor limiting possible motion of Aft and Fwd closure, and small deflections when the motor is pressurized, the level of compression set is considered acceptable.

Mechanical properties of the o-rings have been tested and all o-rings except the o-ring at the sustainer nozzle show good mechanical properties. The results from testing of the o-ring at the sustainer nozzle indicate slight ageing effects. However the compression set values for this o-ring is very low, and accordingly the o-ring will still seal properly during motor operation.

6.5 Propellants

For the tests performed no significant changes in the propellant properties are seen.

The tensile test of both sustainer and booster propellant show acceptable results at all temperatures, and no significant changes since the propellant was manufactures in 1993.

The propellant to insulation/inhibitor bond shows some reduction in strength, however the reduction is considered to be caused by difference in peel-test samples, and not an actual reduction in the bond strength. The results however establish a basis for comparison with future motor surveillance tests.

Propellant burn rate was tested by strand burning. The results were compared with results from 2" motors tested in 1993. Since 2" motors are manufactured by mixing and casting of propellant as a production control, 2" motors could not be manufactured from propellant samples from motor s/n 202. Accordingly strand burning was used to test the propellant burn rate. Taking into account the uncertainties by comparing results from two different tests, the results for both propellants are within expected range.

DMA (Dynamic Mechanical Analysis) has been performed on both propellants at the Norwegian Defence Research Establishment (FFI). Both glass transition temperature and a master curve for the propellants have been established. The results are as expected and confirm that the glass transition temperature for both propellants is well below the minimum operational temperature for the rocket motor.
The established master curve from DMA show acceptable propellant properties and establish a basis for future surveillance tests.

7. CONCLUSION

The surveillance test performed shows that the 8-year-old Penguin MK2 MOD7 rocket motor was in good condition. There was not discovered any ageing effects that would have influenced safety or performance of the motor.

However some slight ageing effects were observed in the following areas:

- O-rings
- Sustainer igniter
- Booster insulation to bulkhead adhesion

The test performed has established essential test data that establish a good reference for future surveillance tests. Accordingly it is strongly recommended to continue surveillance testing of rocket motors at regular intervals to ensure acceptable reliability and safety of the motor as long as it is in operation.

APPENDIX A

BOOSTER IGNITER PRESSURE VS TIME CURVES (3 PAGES)

Nammo NORDIC AMMUNITION COMPANY

TESTREPORT

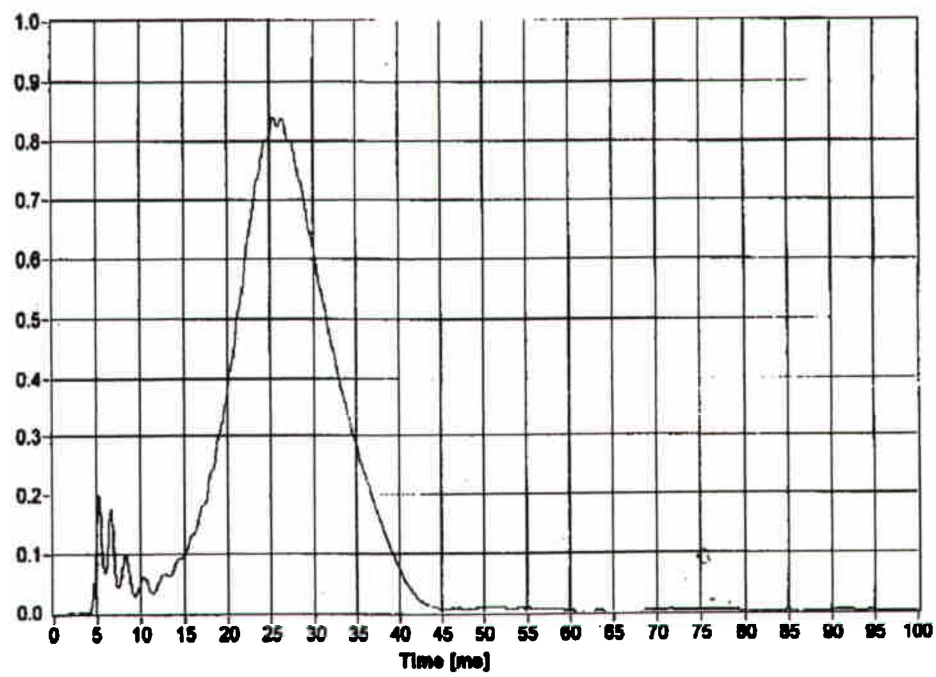
Product	: PENGUIN MK2 MOD7	Part	: BOOSTER IGNITER
Test	: STATIC FIRING IN VENTED BOMB	Test descr.	: 617556-811
Serial no.	: 202 (MOTOR)	Date/time	: 30-10-01/12:09

Firing no. : 98 Cond temp. [°C] : 21 Lot no. : 01-RA-93

Meteorological data : Airtemp [°C] : 6.5 Air humidity [%] : 51 Air press. [mBar] : 935

Lowpassfilter : 14.2 kHz
Samplefreq. : 50 kHz

	CALCULATIONS :	MIN SPEC. :	MAX SPEC. :
Pmax [MPa] :	0.84	0.40	
Time to Pmax [s] :	0.025		0.045
Integral 10-10% [MPa*s] :	0.0119		



T. Halvorsrud
Testconductor

Raufoss A/S
Defence Products Division
Testcenter

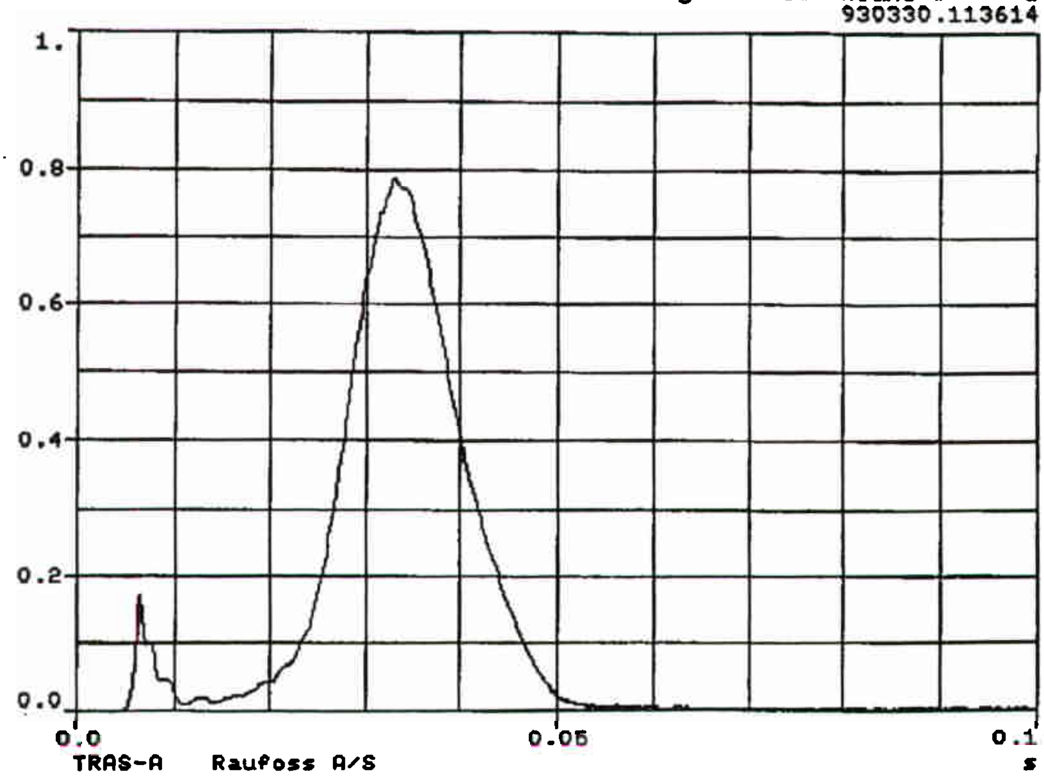
Meas. serial no. 72 Date 1993 3 30
Part report no. 1 Page 1

Product	:Pengin MK2 mod 7 Booster Igniter in Vented Bomb
Specification	:617556-811
Inspection Instr.	:617556-765 E
Lot no.	:01-RA-93

Amp.press. .0962 MPa Temperature -4.0 C Rel. Hum.70.0%

Firing no.	Serial no.	Pmax (MPa)	Time to Pmax (s)	Integral 10-10% (MPa*s)
53	20	.79	.033	.0112
MIN spec.		.4		
MAX spec.			.045	

Penguin MK2 Igniter in Vented Bomb
Ch# 1 Pressure
MPa
Firing # 53 Round # 1
930330.113614



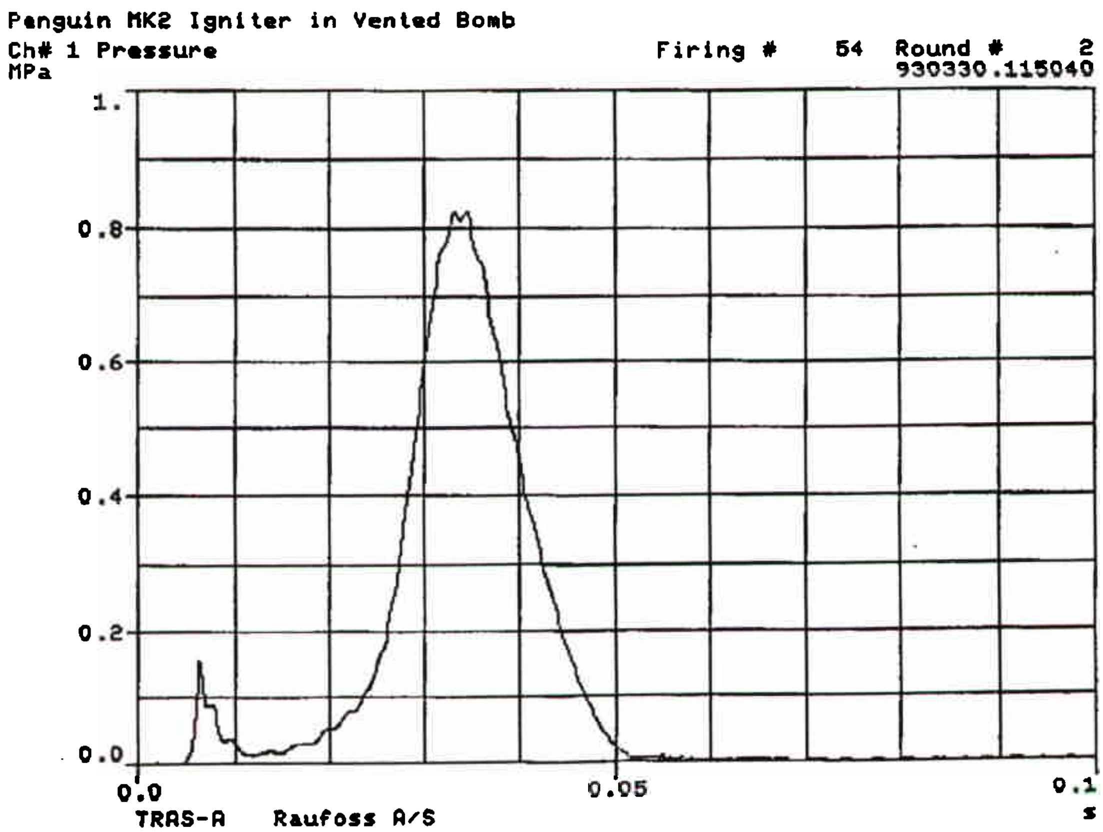
Raufoss A/S
Defence Products Division
Testcenter

Meas. serial no. 72 Date 1993 3 30
Part report no. 2 Page 1

Product	:Pengin MK2 mod 7 Booster Igniter in Vented Bomb
Specification	:617556-811
Inspection Instr.	:617556-765 E
Lot no.	:01-RA-93

Amp.press. .0962 MPa Temperature -4.0 C Rel. Hum.70.0%

Firing no.	Serial no.	Pmax (MPa)	Time to Pmax (s)	Integral 10-10% (MPa*s)
54	50	.83	.033	.0114
MIN spec.		.4		
MAX spec.			.045	



APPENDIX B

SUSTAINER IGNITER PRESSURE VS TIME CURVES (3 PAGES)

Nammo NORDIC AMMUNITION COMPANY

TESTREPORT

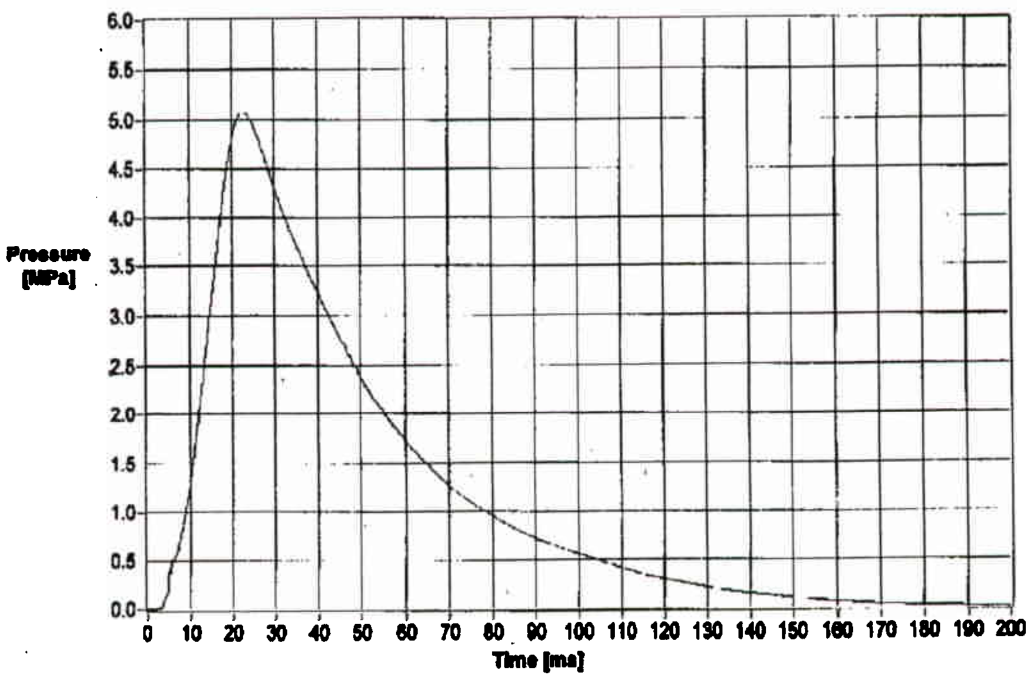
Product	: PENGUIN MK2 MOD6	Part	: SUSTAINER IGNITER
Test	: STATIC FIRING IN VENTED BOMB	Test descr.	: 617489-765
Serial no.	: 202 (MOTOR)	Date/time	: 30-10-01/12:29

Firing no. : 99 Cond temp. [°C] : 21 Lot no. :

Meteorological data : Airtemp [°C] :6.5 Air humidity [%] :51 Air press. [mBar] :936

Lowpassfilter : 14.2 kHz
Samplefreq. : 50 kHz

	CALCULATIONS :	MIN SPEC. :	MAX SPEC. :
Pmax [MPa] :	5.07	3.00	
Time to Pmax [s] :	0.022		0.060
Integral 10-10% [MPa*s] :	0.2104		



T. Halvorsrud
Testleader

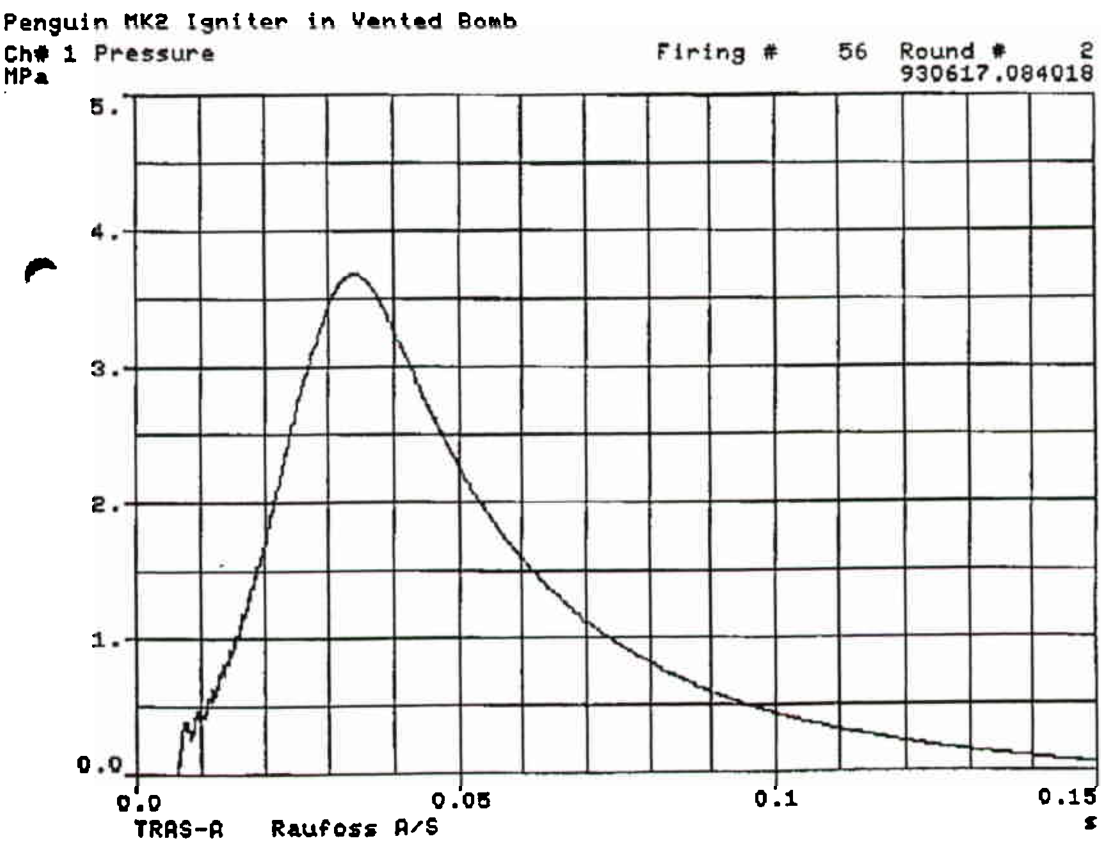
Raufoss A/S
Defence Products Division
Testcenter

Meas. serial no. 71 Date 1993 6 17
Part report no. 2 Page 1

Product :Penguin MK2 mod7 Sustainer Igniter in Vented Bomb
Specification :617489-811
Inspection Instr. :631693-765 B
Lot no. :

Amp.press. .0940 MPa Temperature 7.0 C Rel. Hum.64.0%

Firing no.	Serial no.	Pmax (MPa)	Time to Pmax (s)	Integral 10-10% (MPa*s)
56	33	3.68	.034	.1561
MIN spec.		3.0		
MAX spec.			.060	



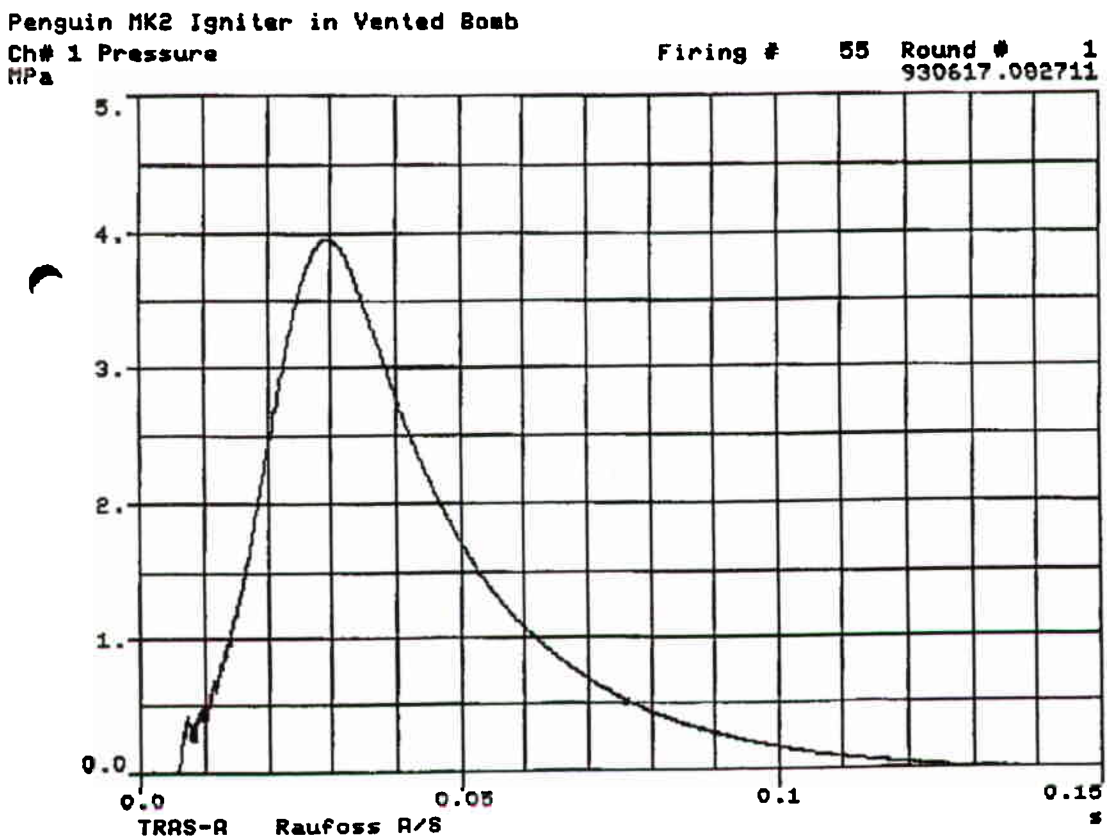
Raufoss A/S
Defence Products Division
Testcenter

Meas. serial no. 71 Date 1993 6 17
Part report no. 1 Page 1

Product :Penguin MK2 mod7 Sustainer Igniter in Vented Bomb
Specification :617489-811
Inspection Instr. :631693-765 B
Lot no. :

Amp.press. .0940 MPa Temperature 7.0 C Rel. Hum.64.0%

Firing no.	Serial no.	Pmax (MPa)	Time to Pmax (s)	Integral 10-10% (MPa*s)
55	36	3.96	.029	.1331
MIN spec.		3.0		
MAX spec.			.060	



APPENDIX C

GLASS TRANSITION TEMPERATURE CURVES (4 PAGES)

TEST REPORT SHEET
Dynamic Mechanical Analysis

Report reference Number : Booster Prop. Motor SN 202

Page 1 of 4 pages

TEST SITE INFORMATION

Laboratory: Forsvarets Forskninginstitutt avd. BM
Date: 18. December 2001
Test Procedure: STANAG 4540
Date Tested: 6.December 2001

TEST CONDITIONS

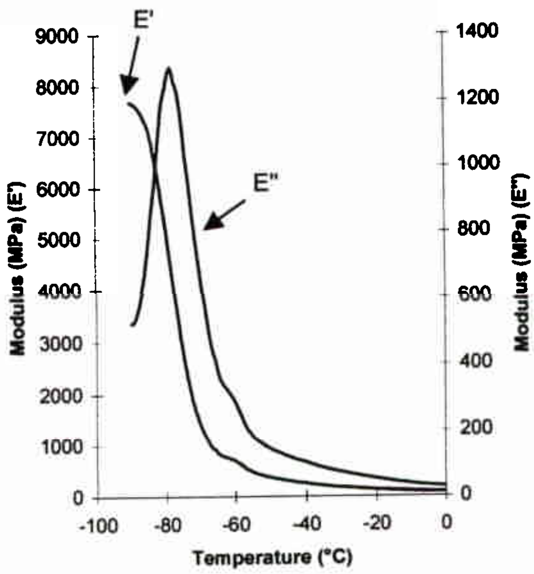
Initial/Final Temperature (°C): -90/0
Iso Temperature & time (°C & min): -90 & 30
Osc Amp (um): 20 Frequency (Hz): 1
Temperature Rate (°C/min): 1
Machine Type: TA Instruments DMA 2980
Grip Type: Dual Cantilever Test Type : Multifrequency

SPECIMEN INFORMATION

Dimension : Length: 40
(mm) Width: 10.51
Thickness : 4.65
Length correction: 20
Form: Rectangular
Preparation Method: Guided knife
Manufacturing Method: NA
Source: NAMMO Raufoss AS
Lot or ID Number: PA-01-007 Motor Series 202
Preconditioning: Temperated at room temperature for at least 24 hours prior to measurement
Conditioning History:
Composition: NA

Component	Percent

RESULTS



T (°C)	E' (GPa)	E" (GPa)	G' (GPa)	G" (GPa)	Tan δ	f (Hz)	Comments :
-90	7673	523			0.068	1.00	
-85	7183	766			0.107	1.00	Tg at peak in E" at -78.29°C
-80	5255	1232			0.234	1.00	
-75	2818	1124			0.399	1.00	
-70	1423	668			0.470	1.00	
-65	852	380			0.446	1.00	
-60	700	288			0.411	1.00	1. parallel
-50	372	145			0.389	1.00	
-40	253	103			0.408	1.00	
-30	175	74			0.423	1.00	
-20	130	54			0.416	1.00	
-10	99	38			0.386	1.00	
0	83	30			0.361	1.00	

Data Sent To: Tore Hjelmås
NAMMO Raufoss AS
Box 162 N-2831 Raufoss

T_g = -78.3 °C at 1.0 Hz

TEST REPORT SHEET
Dynamic Mechanical Analysis

Report reference Number : Sustainer Prop. Motor SN 202

Page 1 of 3 pages

TEST SITE INFORMATION

Laboratory: Forsvarets Forskninginstitutt avd. BM
Date: 18. December 2001
Test Procedure: STANAG 4540
Date Tested: 10. December 2001

TEST CONDITIONS

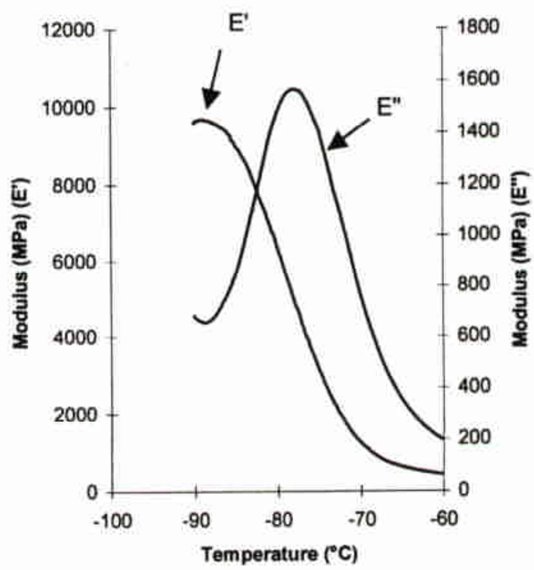
Initial/Final Temperature (°C): -90/-60
Iso Temperature & time (°C & min): -90 & 30
Osc Amp (um): 20 Frequency (Hz): 1
Temperature Rate (°C/min): 1
Machine Type: TA Instruments DMA 2980
Grip Type: Dual Cantilever Test Type : Multifrequency

SPECIMEN INFORMATION

Dimension : Length: 40
(mm) Width: 11.48
Thickness : 4.75
Length correction: 20
Form: Rectangular
Preparation Method: Guided knife
Manufacturing Method: NA
Source: NAMMO Raufoss AS
Lot or ID Number: PA-02-007 Motor Series 202
Preconditioning: Temperated at room temperature for at least 24 hours prior to measurement
Conditioning History:
Composition: NA

Component	Percent

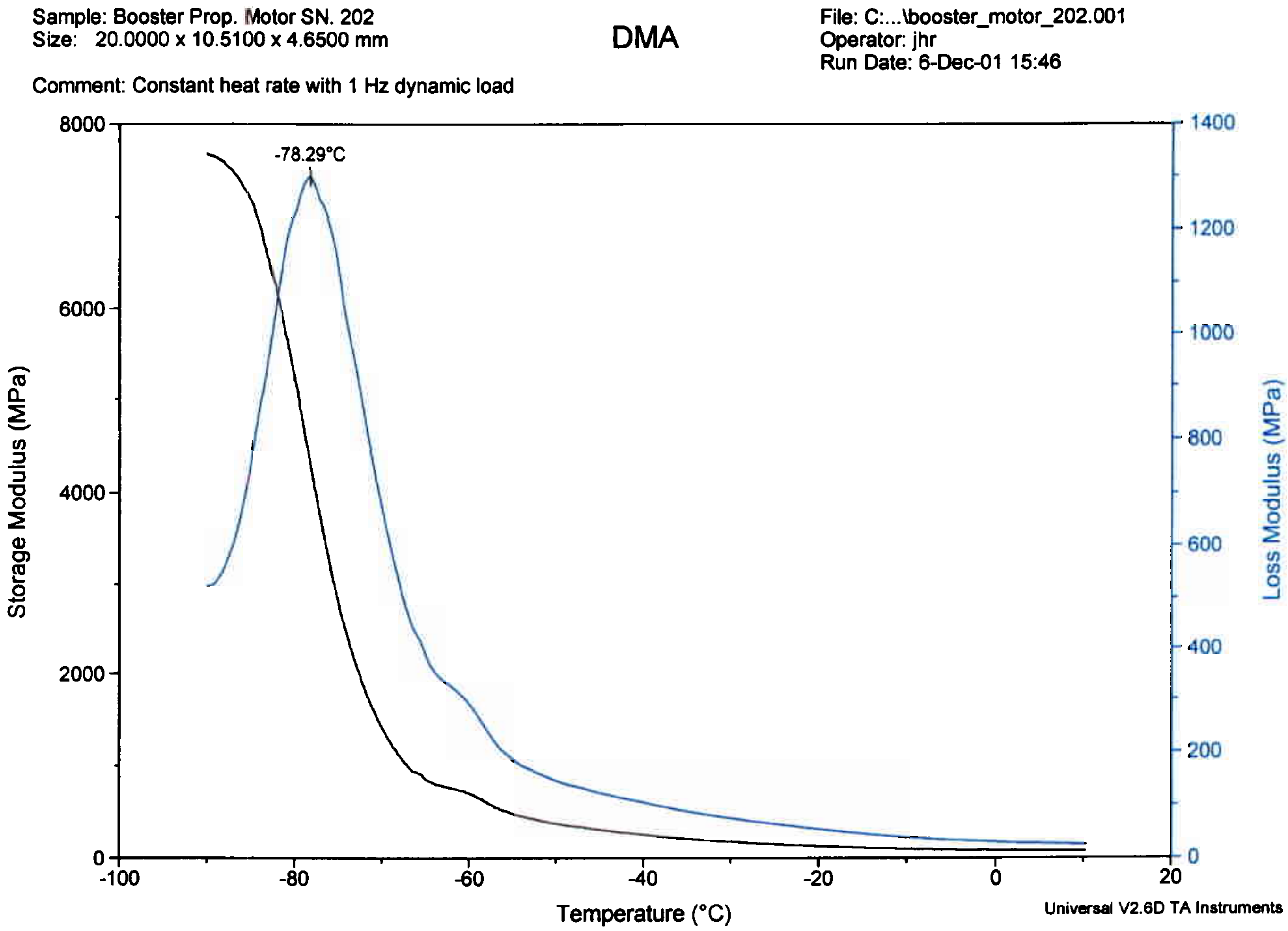
RESULTS

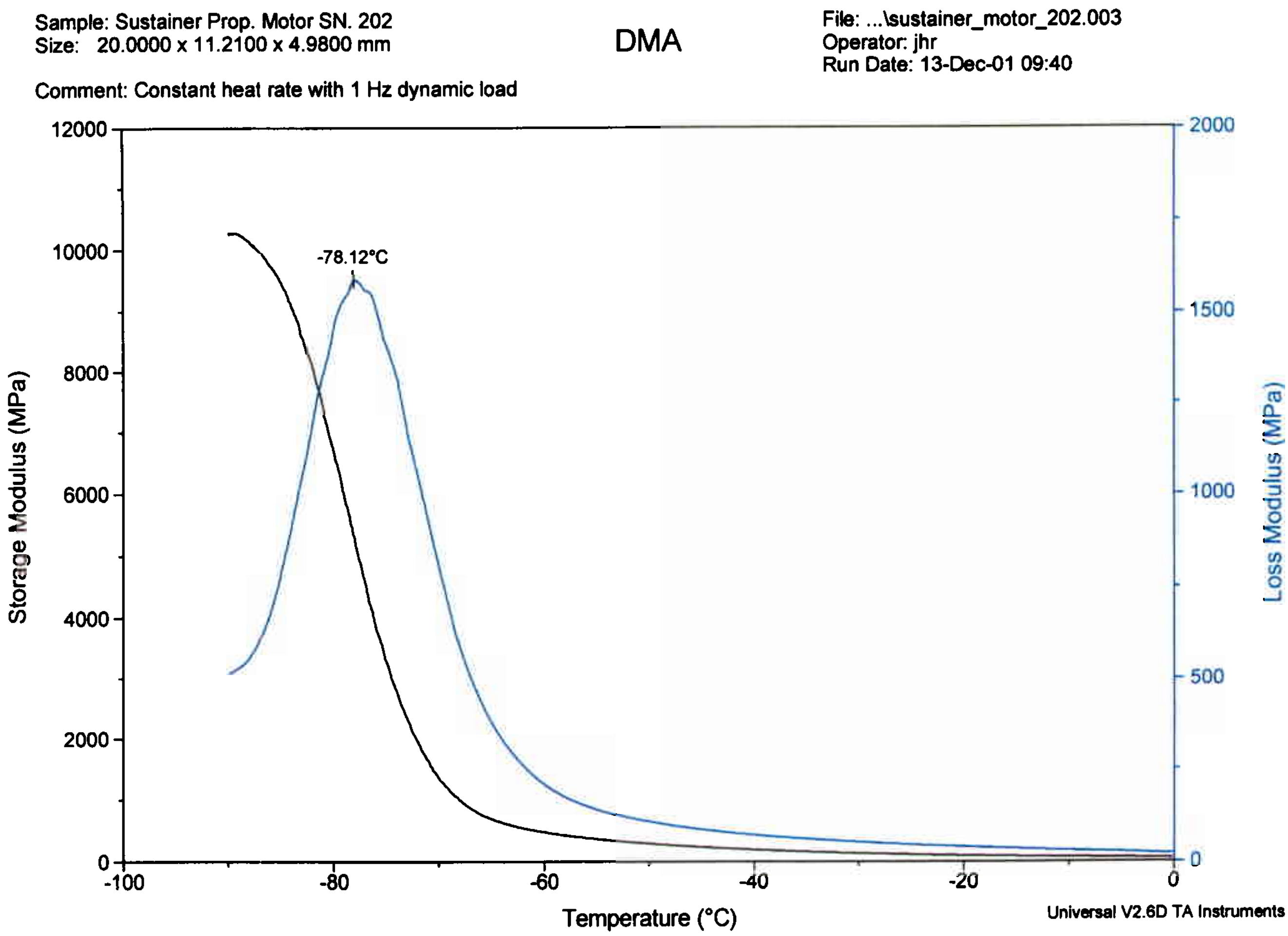


T (°C)	E' (GPa)	E" (GPa)	G' (GPa)	G" (GPa)	Tan δ	f (Hz)	Comments :
-90	9623	680			0.071	1.00	
-88	9614	667			0.069	1.00	Tg at peak in E" at -78.01°C
-86	9359	771			0.082	1.00	
-84	8651	970			0.112	1.00	
-82	7570	1244			0.164	1.00	
-80	6343	1486			0.234	1.00	
-78	4937	1569			0.318	1.00	1. parallel
-76	3654	1486			0.407	1.00	
-72	1793	1025			0.572	1.00	
-68	891	552			0.620	1.00	
-64	574	306			0.534	1.00	
-60	441	199			0.451	1.00	

Data Sent To: Tore Hjelmås
NAMMO Raufoss AS
Box 162 N-2831 Raufoss

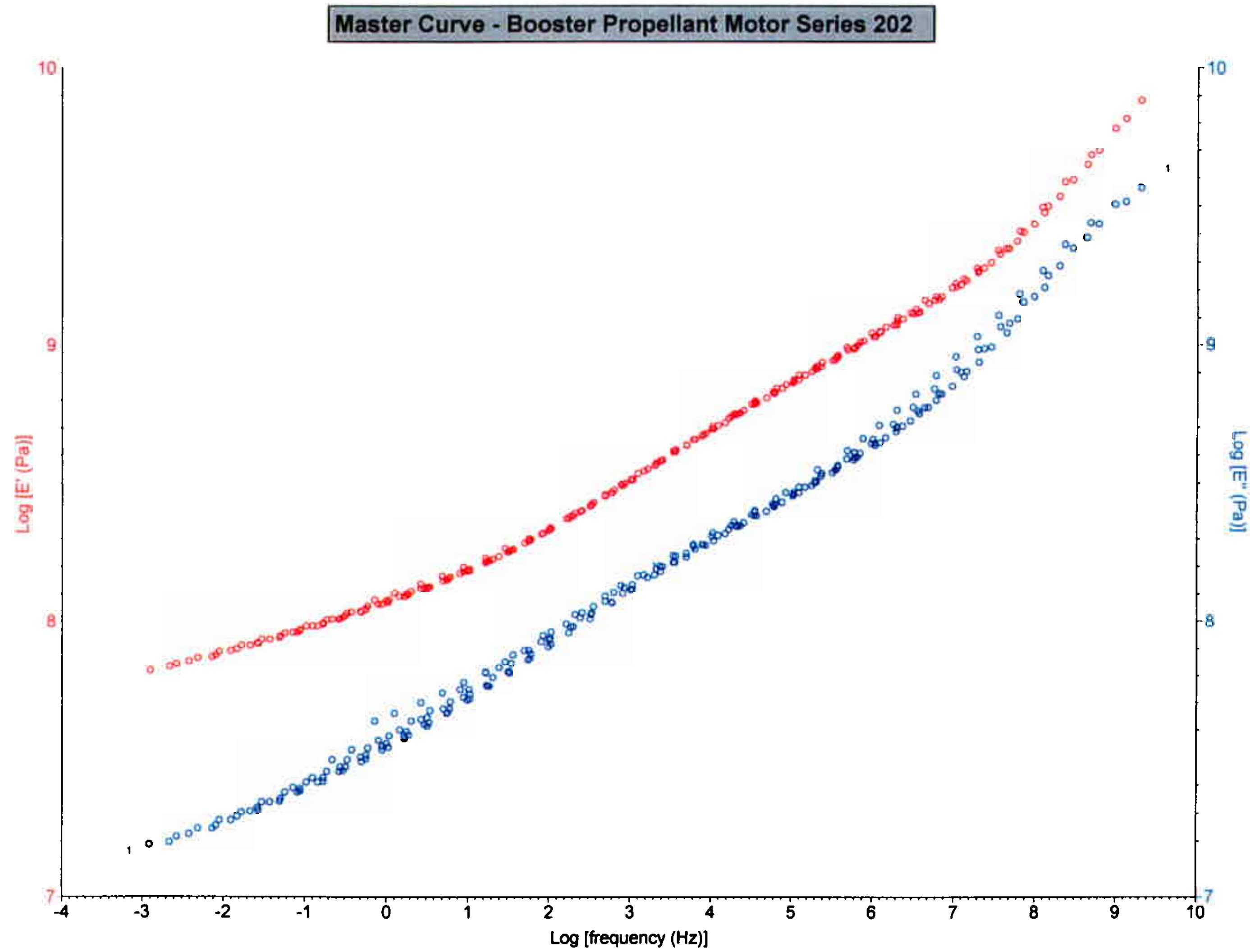
T_g = -78.0 °C at 1.0 Hz

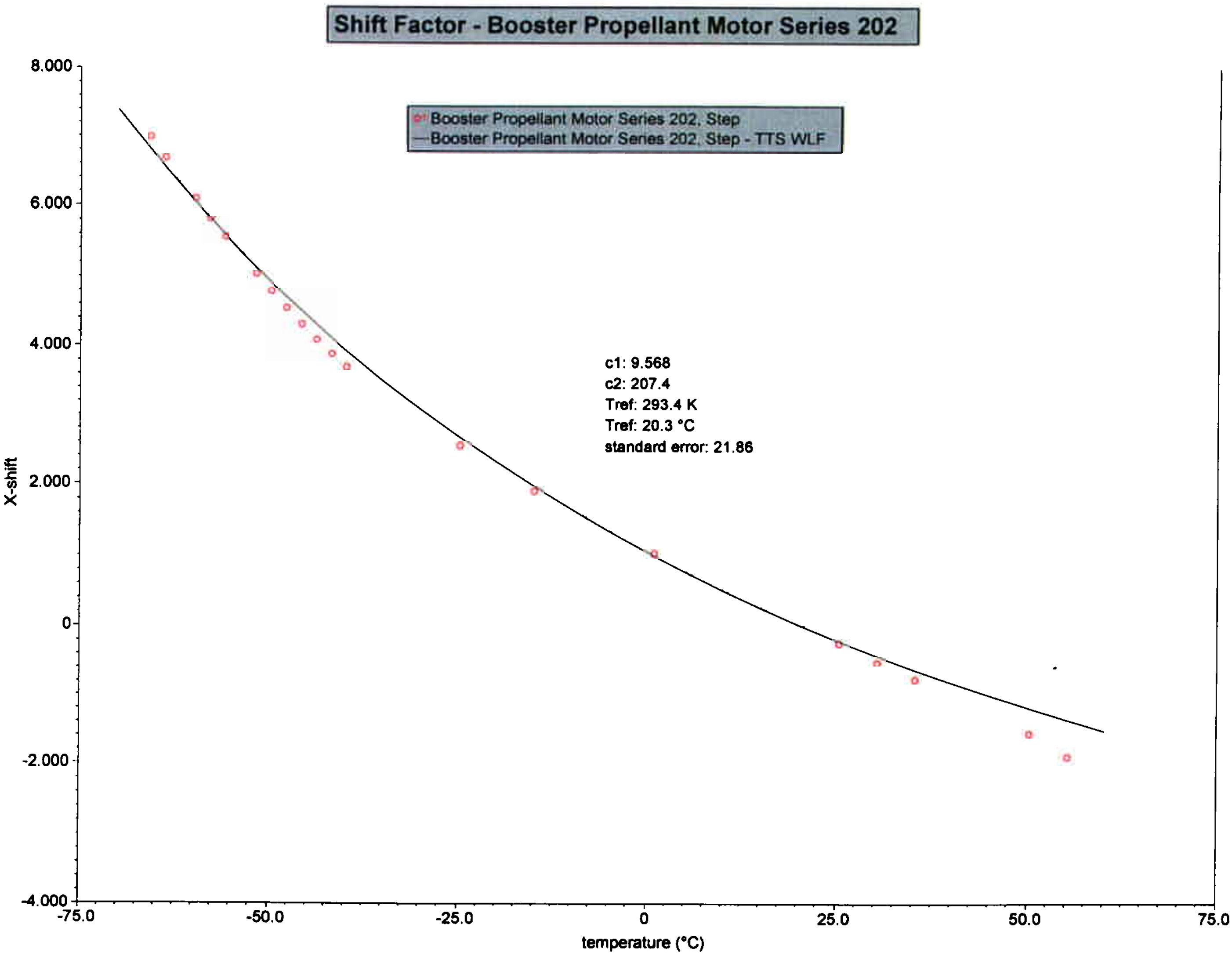

Sample: Booster Prop. Motor SN. 202
Size: 20.0000 x 10.5100 x 4.6500 mm
DMA
File: C:...\booster_motor_202.001
Operator: jhr
Run Date: 6-Dec-01 15:46
Comment: Constant heat rate with 1 Hz dynamic load
-78.29°C
Storage Modulus (MPa)
Loss Modulus (MPa)
8000
6000
4000
2000
0
1400
1200
1000
800
600
400
200
0
-100
-80
-60
-40
-20
0
20
Temperature (°C)
Universal V2.6D TA Instruments

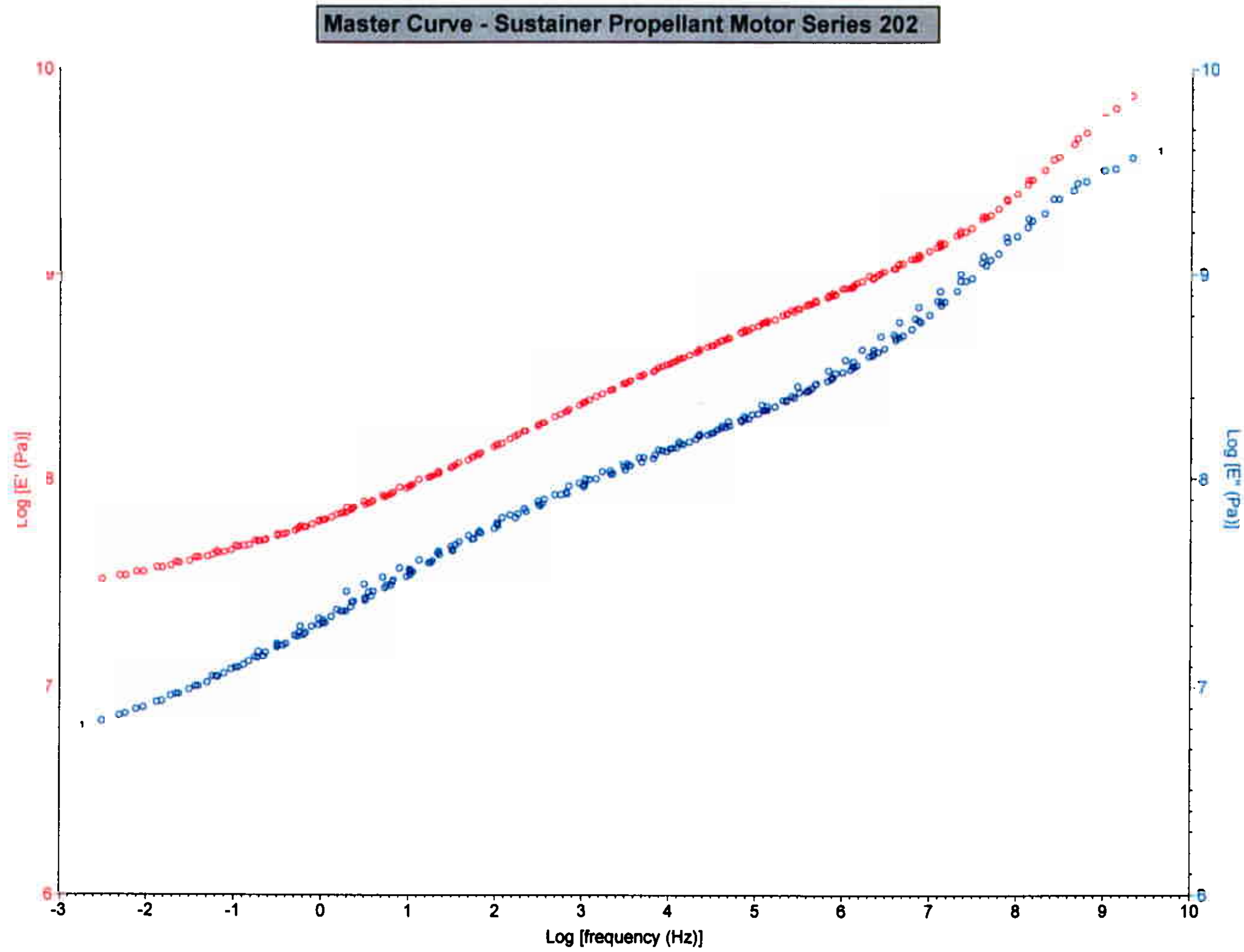

Sample: Sustainer Prop. Motor SN. 202
Size: 20.0000 x 11.2100 x 4.9800 mm
DMA
File: ...\sustainer_motor_202.003
Operator: jhr
Run Date: 13-Dec-01 09:40
Comment: Constant heat rate with 1 Hz dynamic load
-78.12°C
Storage Modulus (MPa)
Loss Modulus (MPa)
Temperature (°C)
Universal V2.6D TA Instruments

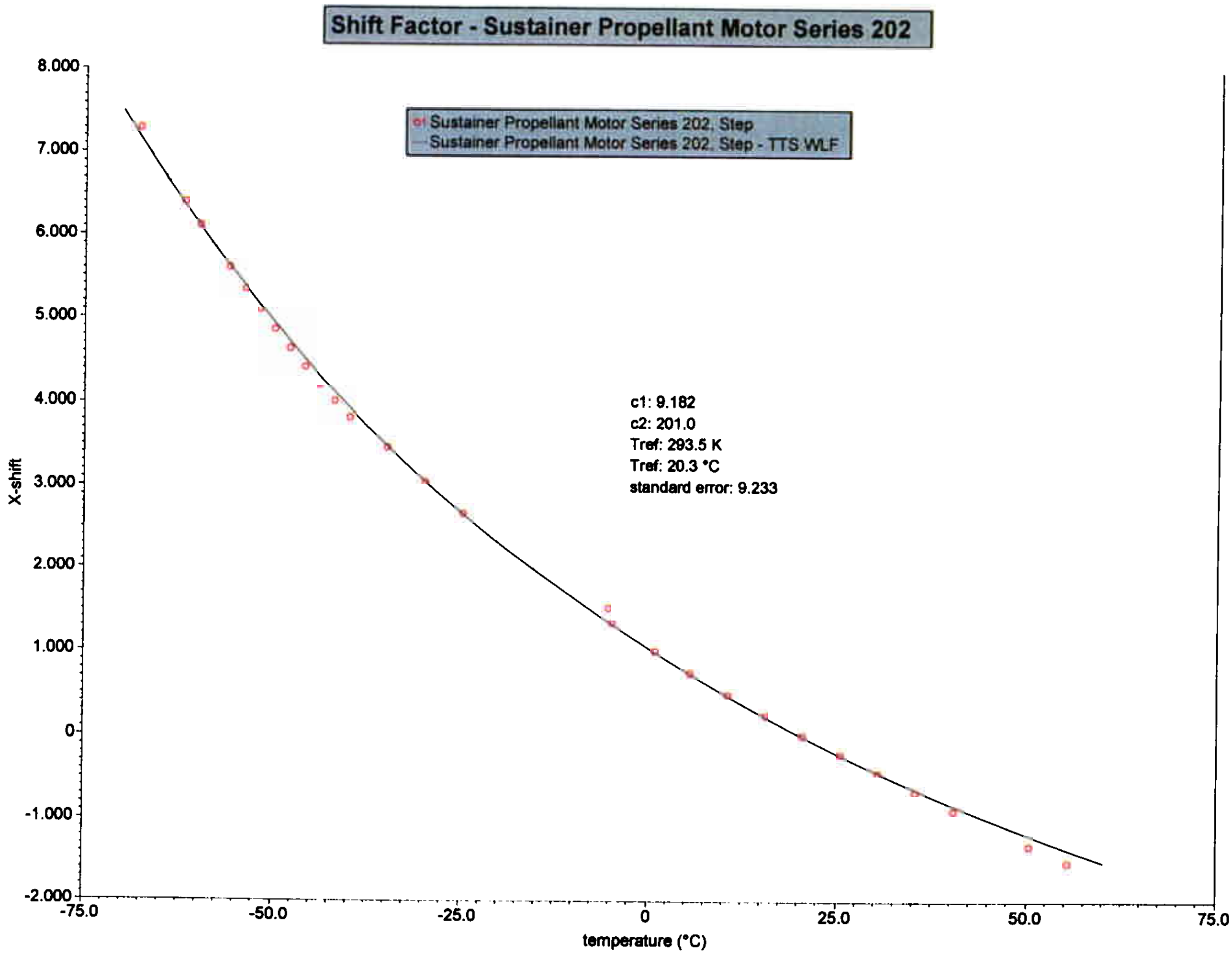
APPENDIX D

MASTER CURVES (4 PAGES)


Master Curve - Booster Propellant Motor Series 202
Log [E' (Pa)]
Log [E'' (Pa)]
Log [frequency (Hz)]
10
9
8
7
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10


Shift Factor - Booster Propellant Motor Series 202
Booster Propellant Motor Series 202, Step
Booster Propellant Motor Series 202, Step - TTS WLF
c1: 9.568
c2: 207.4
Tref: 293.4 K
Tref: 20.3 °C
standard error: 21.86
X-shift
8.000
6.000
4.000
2.000
0
-2.000
-4.000
-75.0
-50.0
-25.0
0
25.0
50.0
75.0
temperature (°C)


Master Curve - Sustainer Propellant Motor Series 202
Log [E' (Pa)]
Log [E" (Pa)]
Log [frequency (Hz)]
10
9
8
7
6
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10


Shift Factor - Sustainer Propellant Motor Series 202
Sustainer Propellant Motor Series 202, Step
Sustainer Propellant Motor Series 202, Step - TTS WLF
c1: 9.182
c2: 201.0
Tref: 293.5 K
Tref: 20.3 °C
standard error: 9.233
X-shift
temperature (°C)
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0
-1.000
-2.000
-75.0
-50.0
-25.0
0
25.0
50.0
75.0

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