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A Rotary Compressor for an Aircraft Pod Cooling System - The Final Chapter

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I ABSTRACT

This paper brings to a close the trials and tribulations of a refrigerant compressor for a fighter aircraft. Two papers have been given at previous conferences: Design and Test Results of a Sliding Vane Rotary Compressor For an Aircraft Pod Cooling System (1986) and Further Results of a Rotary Compressor for an Aircraft Pod Cooling System (1988).

The compressor for this application, as reported in the 1988 paper, is operated at 5600 RPM and is the heart of an R114 cooling system used to cool densely packaged, high technology electronics at ambient extremes from +48 F to +195 F environments. The compressor is a semi-hermetic, 400 Hz motor-driven sliding vane piston type.

In the last four (4) years over 1000 of these systems have been fielded. After a nearly disastrous start, the production of these compressors has become a routine, predictable process. Operation in the field has been outstanding with no failures of compressing elements to date. This includes combat operation during Operation Desert Storm. This system continues to support advanced capabilities of F-15 and F-16 aircraft of the U.S. Air Force.

This paper details the changes in the compressing element in order to operate at 5600 RPM, which centers on the addition of active bearings between the roller and the shaft as well as in the shaft to ground bearings. In addition it also gives details of the material changes to provide adequate life of the shaft and bearing plates. Further highlighted is the success of a nonmetallic vane material and a patent pending sealing ring system which also use nonmetallics.

II SYSTEM REVIEW

LANTIRN is a highly sophisticated navigation and targeting system that increases the combat effectiveness of tactical fighter aircraft. LANTIRN is an acronym for Low Altitude Navigation Targeting InfraRed for Night. It provides high-resolution infrared imagery and precision targeting functions for high speed, low altitude and air-to-ground weapon delivery over any terrain at night and in limited visibility of smoke, dust, dry haze and smog.

The system consists of two units, see Figure 1, a Navigation pod and a Targeting pod. The pods are self-contained systems which operate independently or in conjunction and incorporate a highly modular design for ease of maintenance and maximum mission flexibility.

The system has reached mature production status and operates on both F15E and F16C/D aircraft. The system performed admirably during Desert Storm and continues to be a model program in terms of quality, delivery and reliability.

Each pod contains its own separate Environmental Control Unit (ECU) subsystem. The ECU provides a conditioned liquid coolant to the densely packaged electronic components, see Figure 2. The coolant is supplied in a temperature range of +40 to +86 F (+5 C to +30 C). The heart of the system is an R114 vapor compression system, which employs the aforementioned rotary compressor. The compressor is commanded "ON" anytime the ambient temperature is between +48 F (+14 C) and +195 F (+91 C) and operates in negative gravity environments up to 12 seconds.

In order to increase fielded reliability, each system delivered is subjected to multiple Environment Stress Screening (ESS) testing. This test consist of a 10 minute vertical axis vibration and a minimum of 3 thermal cycles where it is operated over the range of -40 F to +110 F (-40 C to +43 C). Operating conditions are monitored during the test to verify performance is continually met along the test spectrum. The temperature profile also contains non-operating sections of -65 F (-53 C) and +185 F (+85 C). The thermal profile is shown in Figure 3. During testing, the compressor is thoroughly soaked to -40 F (-40 C). The ambient temperature is raised at a rate of +9 F (+5 C) per minute. The compressor reaches turn "ON" condition +48 F (+14 C) in approximately 9 minutes. While the ambient temperature has warmed, the compressor element is still at extreme cold as is the oil and the refrigerant. The compressor design, with four (4) active bearings, the Torlon vane and sealing rings, has held up extremely well to this low lubricity condition and has yet to fail in this testing.

A complete qualification test was completed which included a high vibration duration test. Extensive development tests were also performed, including a 72 hour inverted operation test. During this test, the system performance was degraded 20%, presumably from loss in heat exchanger efficiencies. The compressor showed no signs of wear from this test.

III COMPRESSING ELEMENT DESIGN

The compressing element design is depicted in Figure 4. The basic design is the sliding vane with eccentrically set rolling piston. There are, however, several key differences between this design and the standard domestic use of this product.

Active Shaft to Ground Bearings: An active bearing system was chosen for the shaft to ground for three reasons: 1) the compressor must operate over a wide variation in environmental conditions; 2) the higher bearing loads brought on by the increase in speed and 3) the desire to make the system operate at any attitude including upside-down.

Active Shaft to Roller Bearings: For reasons similar to the above, active bearings were added to the roller to shaft contact. There are many conditions where adequate lubrication of the roller to shaft was not a guaranteed condition, such as low temperature start up and reversed attitude. Similarly, the higher speed created problems with lubricity requirements here. One advantage is that noise from active bearings is not a particularly sensitive subject as compared to a domestic application. Because of the space limitations selection of a bearing with the right quantity of needles and their diameter became critical.

Roller Sealing Rings: The bearing in the shaft to roller application are pressed into the roller. In selecting this method of installation it was realized that the roller wall thickness would be fairly thin and only a limited land area would exist at the roller to endplate interface. In order to provide adequate wear at this interface, rings on both ends of the roller were added, see Figure 5. In the design of the rings, it was assumed that the pressure inside the roller is slightly greater than at the ends of the roller. Taking advantage of this pressure differential, it was decided to leave the rings loose fitting, making the assumption they would be pushed up against the endplates. In addition, the rings are made of Torlon[1] because of its proven wear characteristics. In actual practice, the clearance between the rings and the roller inside diameter must be held extremely tight in order to prevent leakage down the side of the ring, but yet, not so tight that the rings are prevented from moving under pressure to the endplates. Holding the Torlon rings to a tight tolerance has not proven to be as difficult as previously thought as the rings have proven to be extremely dimensionally stable under proper production care. A patent application is pending for this design.

Thrust Bearing: A lower thrust bearing was added to the assembly in order to absorb some of the high vertical loads of fighter aircraft vibration. There was limited land area left on the shaft to endplate interface to accomplish this task. This thrust bearing is also made of Torlon and has oiling groves for better lubricity.

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1. Torlon is a Poly (amide-imide) thermal plastic and is a registered tradename of Amoco Chemicals Corp.

IV MATERIAL SELECTION

Material selection for the compressing element, shown in Table 1, was based on three factors: experience, availability and the judicious use of Torlon. The major parts of the rotating group; the cylinder, the roller and the top and bottom bearing plates are all made out of ductile cast iron. Cast iron provides not only a good method for manufacture of parts to near net shape, but also has high oil retention characteristics. The shaft is carburized steel for high strength.

Of significant interest is the use of Torlon for bearing, sealing and vane material. Four (4) parts are Torlon; the sliding vane, the thrust bearing, and the two sealing rings. These parts have demonstrated very high wear resistance in this application without a single field failure to date. In the early going, there was much concern with getting to repeatable manufacturing and shape retention in the presence of heat and moisture. The four (4) parts are all injection molded to near net shape and then final machined to precise tolerances. By strictly controlling this process dimensional repeatability has been very good. Also believed to be key to the process is the minimization of moisture absorption. Special packaging provisions were put in place to maintain a moisture-free storage environment, by use of a sealed bag with a desicant. No warpage or dimensional changes have ever been encountered during the entire manufacturing run. The theory of moisture absorption warpage has been viewed as mythical.

V CLOSEOUT

The LANTIRN ECU has been a very successful program, providing highly reliable service to the U.S. Air Force, including severe duty during Desert Storm. In nearly 3 years of service there has not been a failure of compressing elements anywhere in spite of some fairly adverse environments. Only a handful of electrical connector failures have caused field removals.

Up next for this compressor will be to ensure compatibility with replacement refrigerants. The compressing element with the four needle bearings has demonstrated ruggedness even in low lubrication conditions which suggests it will be compatible with this new application.

In conclusion, the active bearing design with Torlon vane, thrust bearing and sealing rings has successfully mastered the 5600 RPM and the difficult environment of the fighter aircraft application.

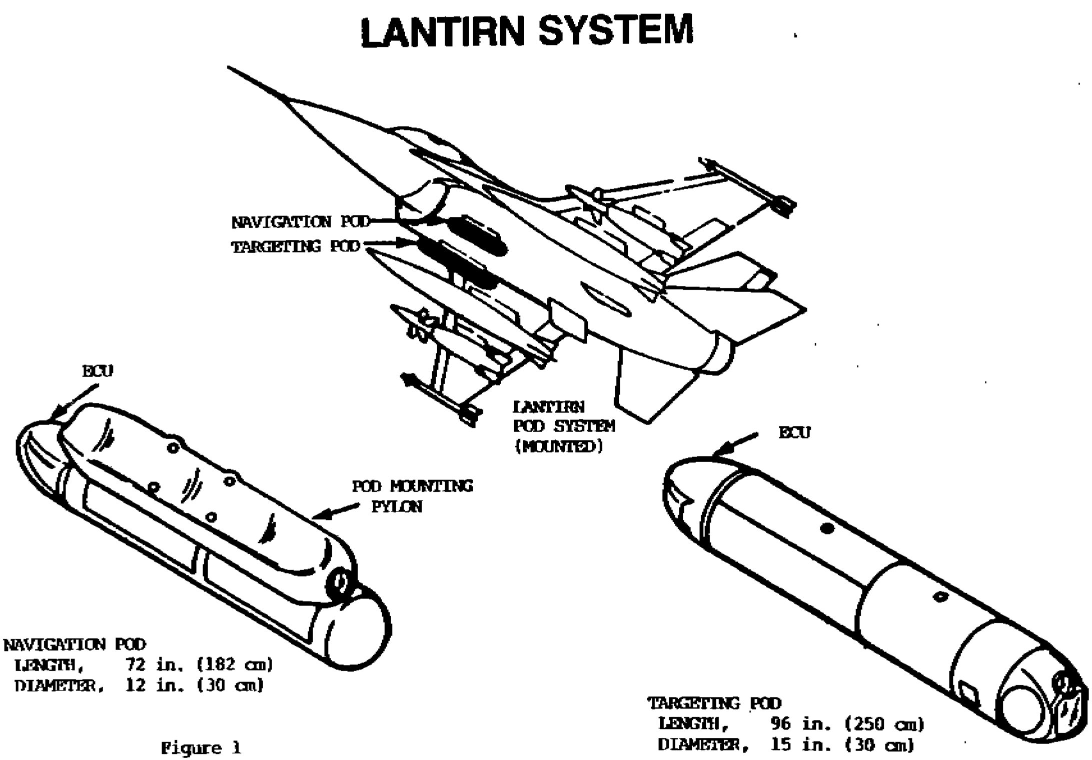
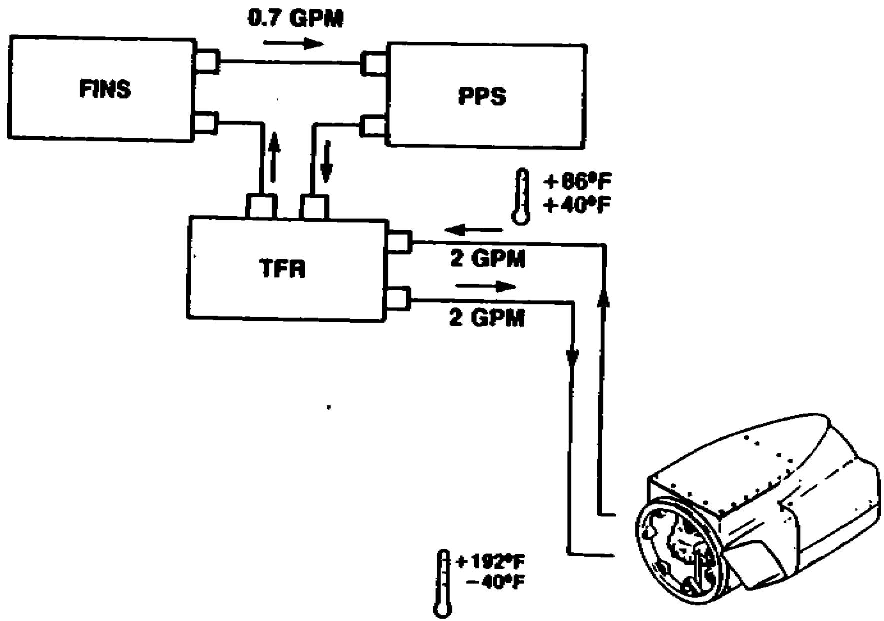


Figure 1

LANTIRN POD SET WITH ECU'S

Figure 2

ENVIRONMENTAL CONTROL SYSTEM/ELECTRONICS INTERFACE



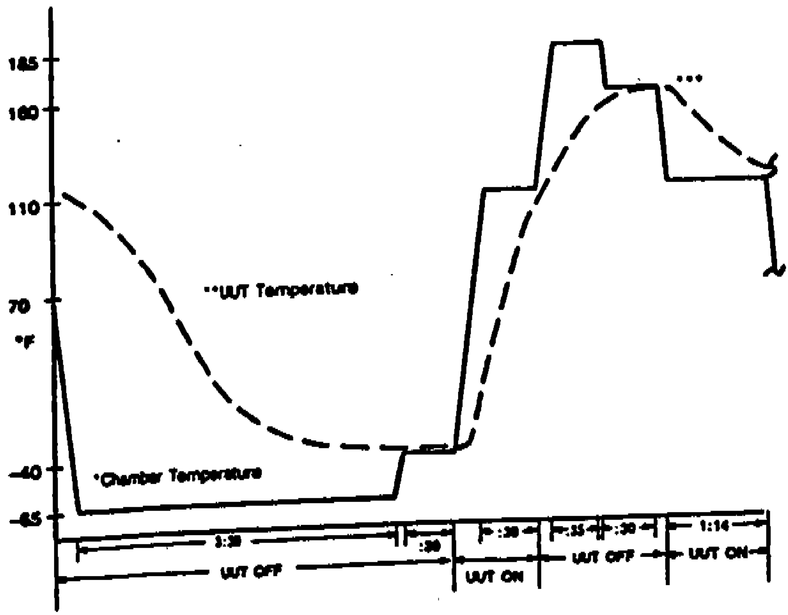


Figure 3

ESS THERMAL PROFILE

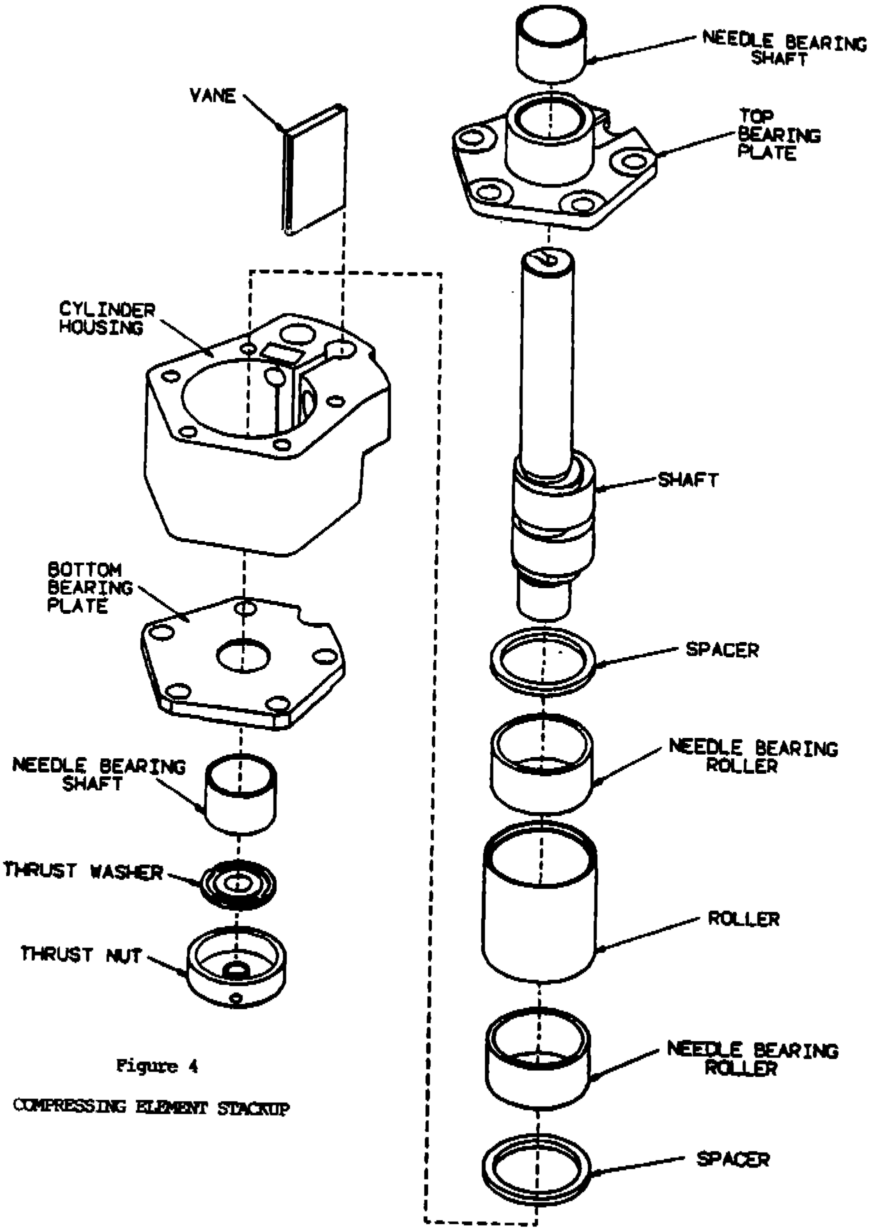


Figure 4

COMPRESSING ELEMENT STACKUP

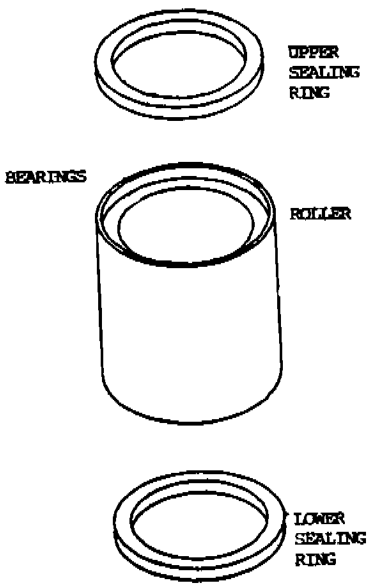


Figure 5

ROLLER WITH SEALING RINGS