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Item No. 001AL

Technical Progress Report

Development of a Low Noise 10 K J-T Refrigeration System

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1.0 Introduction

This report summarises work done on Contract No. N00014-86-C-0301 in the period from August 16, 1989 to February 15, ~~1990~~ on the development of a low noise Joule-Thomson, microminiature refrigeration system designed for 10K operation. Good progress has been made on the compressor and on the waterknife to be used for the fabrication of the refrigerators. Work on the refrigerator itself is progressing well. Difficulties which had been experienced previously resulting in the warming of the nitrogen stage precooler appear to be due to inefficiency of the final stage laminar flow heat exchanger. This inefficiency is strongly dependent upon the mass flow through this stage, and difficulty in controlling this to the required precision caused the wide range of variations in the performance of otherwise similar coolers. Details of this and the work on the compressor and waterknife are described below.

2.0 Compressor

2.1 Review of Hydraulic vs Pneumatic Operation

It is useful to review the relative merits of the use of hydraulic and pneumatic actuation of the slow compressor. Hydraulic fluid is virtually incompressible and as a result in such a system the motive power from the pump is transferred to the hydraulic cylinder with excellent efficiency. However, for the same reason, i.e., that the fluid is incompressible, means must be provided for overpressure relief to prevent an unacceptably large pressure rise in the system when the piston reaches the end of its stroke. The release of this pressure then causes heating of the fluid, requiring some auxiliary means for cooling the fluid. The added volume of such a cooler adds mass to the system. These several factors offset most of the advantages of the hydraulic system. In addition, it is awkward to replace any components in an operating hydraulic system without maintaining a substancial back-up supply of hydraulic fluid, which again adds mass to the system.

In a pneumatically operated system, on the other hand, the gas can be cooled in a light-weight radiator. The system is clean and components can readily be replaced without loss of valuable fluid, and the system is light. However, the price one pays for this flexibility is a reduction in efficiency and an increase in the volume of the fluid (air) that one must pump. This reduction in efficiency is traceable to the compressibility of the working fluid, i.e. the compressed air.

In the first stage of a two stage compressor of the type being developed for this program, the volume of compressed air at the operating pressure (11 atm.), which is needed to actuate the pneumatic cylinder which compresses the gas in the cylinder of the clean compressor for the cooler, is approximately equal to the volume accepted in the intake stroke of the clean compressor. If upon the return stroke, the compressed air is expanded down to one atmosphere and is then recompressed to 11 atm. in the air compressor, the volume of air which the air compressor must provide, at 1 atm., is eleven times the volume of clean gas which is compressed. For this reason an air compressor is required with a large volume throughput. This then makes for a bulky, unwieldly system.

A great improvement can be made in the system by operating the compressed air at a slightly higher input pressure, for example at 14 atm., and expanding down to 4 atm. This still results in a net actuating pressure of 10 atm. but requires a volumetric displacement of the drive compressor of only 25% of that of the system operating at the lower pressure described above. An improvement in efficiency also results because the air is compressed only by a factor of 3.5 rather than 11 as in the lower pressure system.

In such a system one obtains most of the benefits of the hydraulic system without inheriting at the same time, the disadvantages. In the past few months we have begun to implement this type of drive, using a lightweight, compact, oil lubricated air compressor capable of operating at an input pressure of 4 atm. and an output pressure of 14 atm. A schematic of the system is shown in Fig. 1.

Initial results are promising, but due to the oil lubrication of the compressor, it has been found necessary to incorporate an oil trap in the high pressure line in order to reduce the amount of oil in the gas stream, to allow the four-way shuttle valve to operate at its proper speed.

2.2 Operating Results

Testing has been done on the new version of the compressor modified for a 5cm stroke so as to reduce the percentage dead volume. This is shown in the photograph, Fig. 2. Operating speed was found to be limited by the original Skinner solenoid valve. This was replaced with a five-port, 4-way Numatics, 2 position spool valve with a larger Cv. Using a small Thomas compressor, shown in the photograph, maximum pressure of 110 atm. was reached in 3 minutes. The operating speed was clearly limited by the volumetric displacement of the small compressor.

Using a larger compressor, a comparable pressure could be reached in 15 seconds. However, this larger compressor was limited to an outlet pressure of 70 atm., limiting the maximum pressure that the clean gas compressor could achieve. Tests were then run using a higher pressure tank of compressed gas as the source.

Using an input pressure of 10 atm. from a tank of gas, an

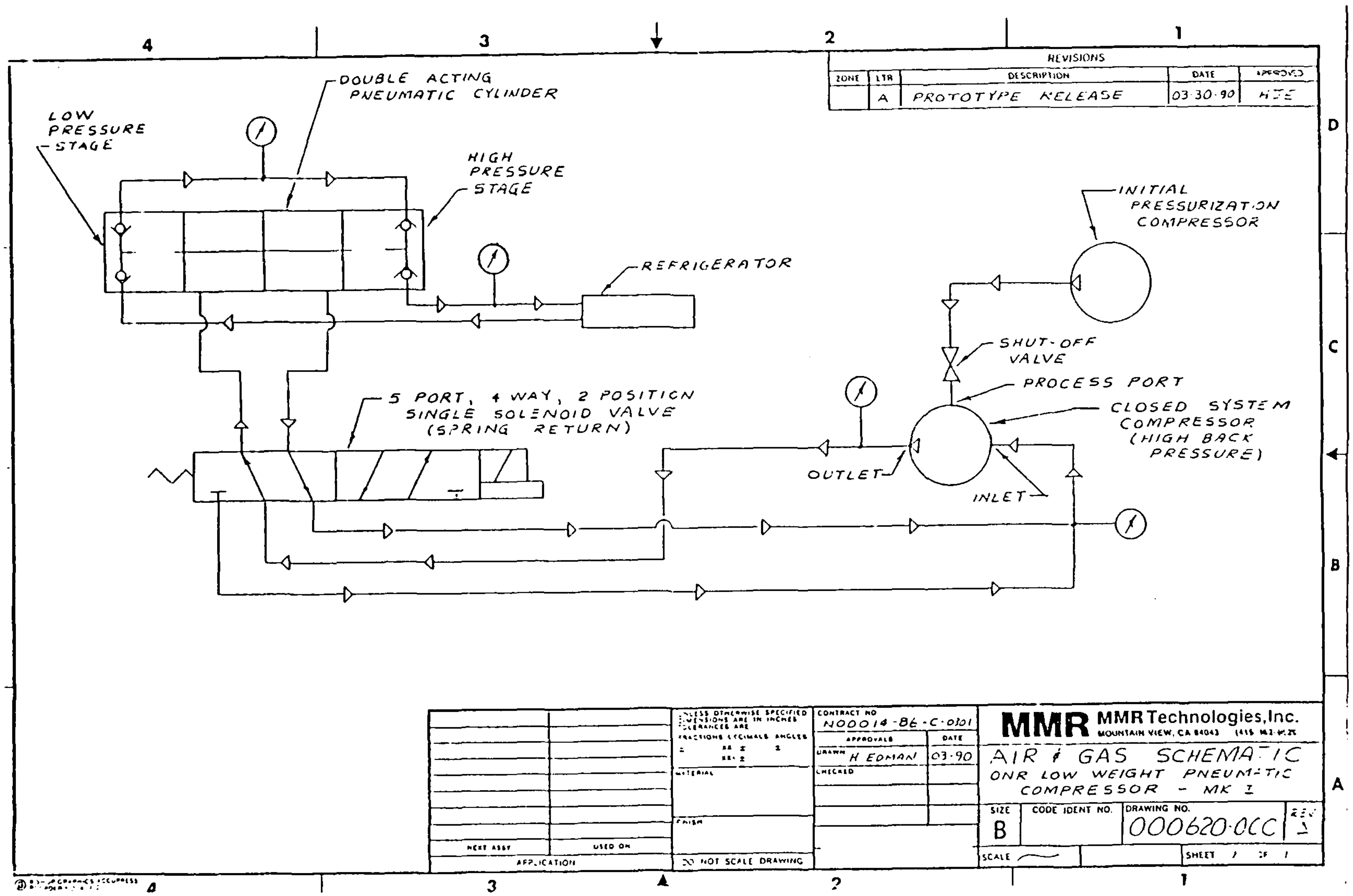

Figure 1. Air and Gas Schematic.
ONR Low Weight Pneumatic Compressor

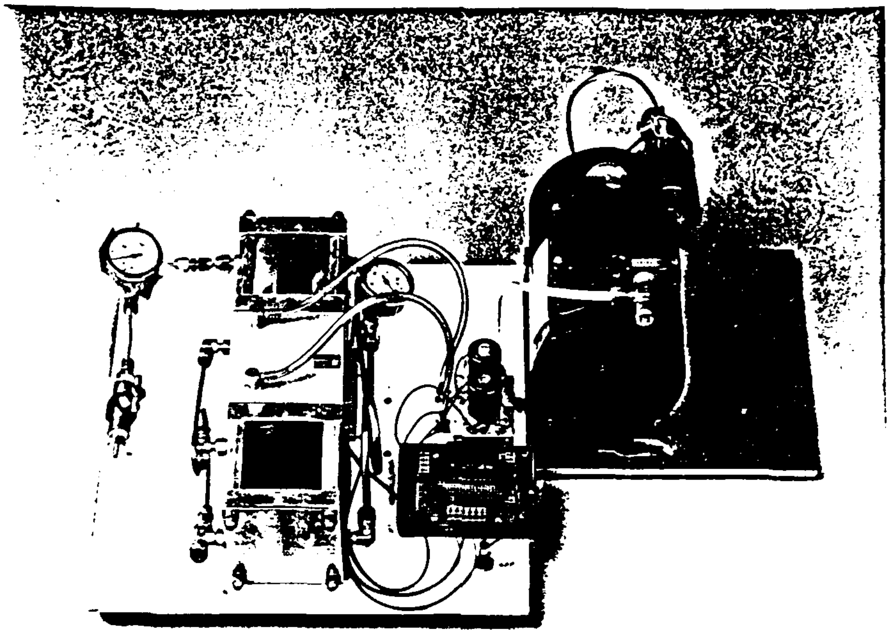

Figure 2. Photograph of 5cm Stroke Pneumatically activated, Two-Stage Compressor

outlet pressure of 130 atm. was reached from the clean gas compressor in 20 seconds. This was then used to operate a standard MMR compressor, having a flow rate of 1.5 l/m at a pressure of 110 atm.

3.0 Waterknife development

Good progress has been made in the development of the miniature waterknife cutting facility. Difficulty had been had in fabrication of the precision nozzles needed for the knife. A tungsten carbide nozzle was designed and fabricated but when tested gave a ragged jet, that appeared to be highly turbulent upon exiting from the orifice and broke up a short distance from the nozzle.

A study was made of the literature to determine what work had been done on the design and fabrication of suitable nozzles of the size needed for our facility. A useful paper was found in the Third International Symposium on Jet Cutting Technology, entitled, "Some Factors Affecting Precision Jet Cutting" by D. H. Saunders. This discusses the use of nozzles of 125μ diameter at pressures of 1400 bars, both of which are well within the range of the needs and capabilities of our facility. In particular, the author pointed out difficulties that had been had with the use of tungsten carbide nozzles, which resulted in poor quality jets and rapid deterioration in the flow due to abrasion of the surface of the nozzle. Much better results were reported with the use of polished sapphire orifices and an example of a working design of the nozzle and nozzle holder was given.

This has enabled us to locate a supplier of nozzles with orifices down to 75μ diameter. An example of one such nozzle is shown in Fig. 3. A selection of these sapphire orifices have been acquired.

The orifice has to be held in a nozzle holder and be sealed against the input pressure of up to 2,000 bars. A successful design has been developed and has been tested at these pressures.

Initial tests were disappointing, however, with the jet still showing turbulence and rapid break-up as the pressure was raised to 1,400 bar. We believe this must be due to develop-

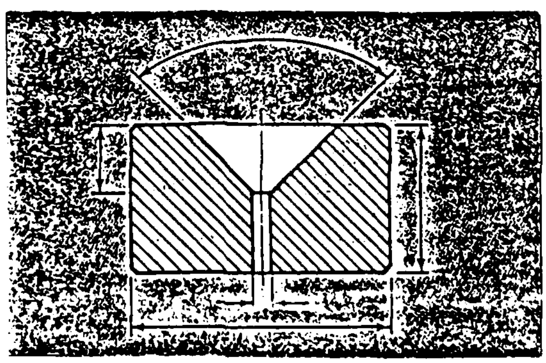

Figure. 3 Sapphire Orifice

ment of turbulence in the feed line prior to the orifice. We have been using a small diameter high pressure line for the feed because of its flexibility which allows the jet to be positioned and repositioned easily. However, from an estimate of the flow, some turbulence could be developing here just ahead of the orifice, which then could lead to the break-up of the jet. In view of this, we have ordered larger diameter tubing and fittings to reduce the flow velocity of the water before it enters the nozzle. This should ensure laminar flow right up to the orifice.

We had proposed originally to use polyethylene oxide (polyox) as an additive to the water as it was known to help the performance of water jets used for fire-fighting. A sample quantity of polyox had been obtained. We were reassured to learn in Saunder's article that polyox does, indeed, improve the stability of water jets in jet cutting orifices at a concentration of as little as 0.1 to 1 %, even in the very small nozzles we propose to use.

The above results are encouraging, as were reports in the literature quoted, of the use of jet cutting for cutting of glazed ceramic tile and plastics at pressures comparable to the 2,000 bar to which we have access. These are materials with properties which are similar to those of materials we were proposing to use the water-knife to cut..

4.0 Refrigerator Fabrication

Work has continued on the refrigerator prototypes, with modifications made in the long out-flow laminar-flow heat exchanger. We had noted that as the temperature drops, the flow through the long, laminar-flow heat exchanger increases, but unless the channel dimensions are in a very narrow range, the flow here can become so large as to reduce the efficiency of this exchanger and thus increase the load on the first stage cooler to the point that the temperature of this stage rises precipitously. Such unstable operation has been seen time and time again. In order to reduce the dependence on the channel dimensions to an acceptable level, the design of the laminar flow exchanger was changed to increase its intrinsic efficiency. While this would also increase the backpressure on the final boiler, this could be kept within acceptable bounds while increasing the effiency substantially.

A revised model has shown much improved performance but further refining in still needed as the shallower channels are more prone to clog if some impurities remain in the gas stream. A compromise between these two factors needs to be reached.

5.0 Personnel

The following persons have been involved in the program:

Refrigerator Fabrication
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Water Knife Tests
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Compressor
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Respectfully submitted,

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