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DEVELOPMENT OF A HYDRAULIC AIR CONDITIONER FOR FOREST MACHINERY

Jean Courteau*

Abstract

This report chronicles the joint development of an air conditioner for forest machinery by FERIC and I&M Electric Rebuilders of Thunder Bay, Ontario. The air conditioner is hydraulically powered and uses a compressed refrigerant gas for heat transfer. Three prototypes were designed, built, and tested in forest operations in Ontario and Quebec.

Introduction

With more attention being given to operator comfort and ergonomics in general, cabs are increasingly being built with large windows for better visibility and with insulation to protect operators from extremes in temperature and noise levels. However, these features tend to hold or increase cab temperatures because of solar radiation, and heat convection either from hydraulic components inside the cab or components surrounding the cab. Temperature is a determinant factor in operator productivity. Since operators of complex equipment must maintain full concentration, it is important to decrease the fatigue associated with an uncomfortably warm environment.

In 1987, FERIC published a report entitled "An Overview of Air Conditioning Equipment in Canadian Forest Equipment"[1]. Results of a survey of FERIC's member companies clearly showed that many of the commercially-available air conditioners were inadequate for woodlands applications. These were more often designed for the automotive market and did not meet the requirements needed to withstand forestry conditions. Therefore, FERIC proposed to promote the development of an air conditioner especially designed for harsh environments. In 1987, FERIC contacted I&M Electric Rebuilders of Thunder Bay, Ontario to undertake this work with FERIC's assistance. This company was chosen for its expertise and experience in air conditioning of forestry equipment. In all, three prototypes were built and then tested in cooperation with forestry companies. This report chronicles the test results.

Experimental Air Conditioner Design Parameters

Unlike automobile or truck air conditioners, air conditioners on forest machinery are subjected to severe external constraints. Vibrations, shocks, dust, machine configuration and condition, and extremes in temperature create a set of unfamiliar conditions for designers of this kind of equipment. These constraints defined the design parameters of the experimental units.

Work Environment

The air conditioner housing must be protected from falling trees and branches. Moreover, outside air must be filtered before entering the cab, and cab pressure should be maintained to at least 0.124 kPa (0.04 psi) to stop dust infiltration. Components must be isolated from shocks and vibrations, and the system must not transmit excessive noise to the cab enclosure.

1 Courteau, J. An overview of air conditioning equipment in Canadian forest equipment. For. Eng., Res. Inst. of Can., Pointe Claire, Technical Note TN-100, 8 p.

* Jean Courteau is a researcher in the Wood Harvesting Group, Eastern Division.
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FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GENIE FORESTIER
143 Place Frontenac
Pointe Claire, Québec
Canada H9R 4Z7
(514) 694-1140
201-2112 West Broadway
Vancouver, B.C.
Canada V6K 2C8
(604) 732-3711

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Dimensions

Because the air conditioner will be mounted on a variety of machines, its dimensions should allow installation on the smallest cabs, as well as those equipped with roof protectors. Therefore, the recommended dimensions should not exceed 0.30 m in height, 1.0 m in length and 0.65 m in width.

Power Source

Unlike conventional systems that need an electrical source and a separate mechanical power source to turn the compressor, it is recommended that forest equipment air conditioners contain all of these components in the same housing. The option chosen to eliminate the problem of external power supply sources was to drive all prototype components with a single hydraulic motor powered by the hydraulic system of the carrier through two hoses. A hydraulic drive provides an added advantage in that the majority of forest equipment mechanics are proficient in dealing with hydraulic systems.

Service

In the event of breakdown, it would be preferable if the unit could be easily removed, to be replaced temporarily while repairs are carried out in a shop. Maintenance would be facilitated if it could be done without having to open up the unit. Therefore, the service valves, air filter and the sight glass of the receiver-dryer-filter should be accessible from outside.

Installation Time

The air conditioner should be self-contained to avoid the need for multiple connections and also to simplify the installation. Installation time should not exceed two person-days. To stay within the price range currently accepted by the industry, the installed cost should be below $4500.

Test Results

Three prototypes were built in an attempt to meet the criteria described in the preceding section. All were rooftop installations powered by a hydraulic motor.

First Prototype (1987)

The first prototype was tested in 1987 at Canadian Pacific Forest Products Limited's operations, near Thunder Bay, Ontario. This system was completely mechanical; even the refrigeration control was done mechanically by means of bellows and levers. All control and process components were contained in the same housing.

The unit, which had a cooling capacity of 4600 watts, was mounted on a Caterpillar model 14G motor grader assigned to road maintenance. The compressor was driven by a hydraulic motor which was powered by the hydraulic system on the grader. The same motor also powered the condenser and evaporator fans. A hydraulic shut-off valve was used as a safety against high or low pressures in the air conditioning system.

In general, the results were disappointing. The air conditioner output was satisfactory, but control problems, both with the hydraulics and cab temperature, were impossible to solve. The grader was not equipped with an auxiliary hydraulic circuit, and thus part of the flow from the main pump was used. Since the grader had a constant pressure hydraulic system, the flow had to be controlled with a regulator which caused overheating of the hydraulics and failure of the compressor shut-off valve on the air conditioner. Although this valve was replaced by a sturdier model, a pressure drop of 1380 kPa (400 psi) across the flow regulator caused overheating to continue. The air conditioner was removed after only a week of trial.

Second Prototype (1988)

The experience of the preceding year and the lack of mechanical refrigeration controls on the market, prompted the incorporation of a self-generating electrical control system on the second prototype, which was built in 1988. The unit was again tested at Canadian Pacific Forest Products, this time installed on a Koehring K3FF feller-forwarder.

The cooling capacity was increased to 5000 watts. High output fans were installed, as well as a drive belt linking the hydraulic motor to the compressor, fan-drive shaft and the electric generator. To avoid the overheating problems incurred during the previous year, a hydraulic pump dedicated to the air conditioner was installed on the carrier.

The second prototype had good cooling capacity and the control system was satisfactory. However, both hydraulic and aerodynamic noise levels were excessive, according to the operator. The smaller fans had to rotate at a higher speed to be efficient, which made them noisy. Furthermore, it was impossible to control their speed. The only means of control provided for the operator, apart from the thermostat, was an on-off switch to start or stop the entire system.

Since the Koehring K3FF has a well-designed soundproofed cab, it is not surprising that the slightest noise would disturb an operator accustomed to a low noise level. To make matters worse, the cab structure had a resonant frequency which corresponded to that generated by the rotating parts of the air conditioner.

Because of the operator's disatisfaction, the prototype was tested for only one week, following which it was removed and modified for the 1989 test season.

Third Prototype (1989)

The 1989 prototype (see Figures 1 and 2), was equipped with wider fans which allowed for a slower rotational speed while maintaining the same air flow. The hydraulic motor, compressor, generator, and fan-drive shaft were mounted on a separate base and isolated from the housing through shock-mounting and acoustic insulation. The housing walls were also stabilized with acoustic insulation. Two other modifications were the addition of a high-capacity air filter, allowing the unit to be used as a pressurizer in case of an air conditioning failure, and the installation of a flow-divider valve, accessible from within the cab, to control fan speed.

This prototype, which had a 5000-watt capacity, was mounted on a Caterpillar D7 tractor belonging to La Compagnie Gaspésia Ltée in Chandler, Quebec. This machine was assigned to road construction.

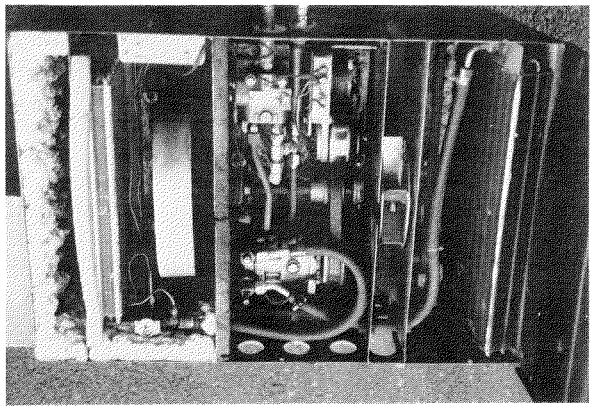
As the D7 tractor was equipped with a constant pressure hydraulic system, a pump dedicated to the air conditioner was installed. Oil was supplied by the hydraulic reservoir of the carrier. The prototype required a working pressure of 5855 kPa (1700 psi) and a flow of 20 L/min, thus adding a 3.9-kW load to the tractor.

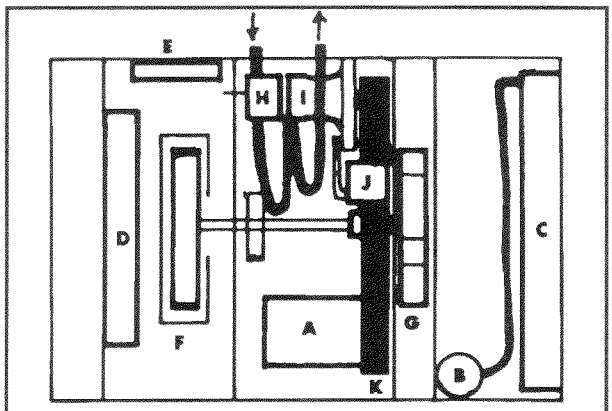
The cooling capacity was adequate according to the operator, despite the large air leaks and a lack of insulation between the engine compartment and the cab. While this unit ran considerably more quietly, the high noise level of the tractor (93 dBA) negated any benefit from this improvement since the operator was forced to wear hearing protection.

Figure 1. Third prototype (1989).

The problems encountered during the tests were all mechanical in nature and were caused by the intense vibration of the tractor. The two fans, which were of welded aluminum construction, had to be replaced by a riveted stainless steel design. Another problem was the failure of the flow divider controller which was in reality, only a makeshift installation.

This air conditioner remained in use for a period of 4 months between June and October 1989.





SIMPLIFIED SCHEMATIC OF THE COMPONENT LAYOUT

LEGEND			
A	compressor	F	fan (cold air to cab)
B	receiver dryer filter	G	fan (hot air exhaust)
C	condensor	H	flow controller
D	evaporator	I	hydraulic motor
E	high low pressure switch	J	generator
		K	drive belt

Figure 2. Schematic of 1989 prototype.

Discussion

Installation Time

The 1987 prototype was installed in only 4 hours, while 12 hours were required for the 1988 prototype and 14 hours for the 1989 unit. The latter installations took longer because protective housings had to be fabricated

(4 hours of labour); this was not necessary on the grader used in 1987. Moreover, an extra hydraulic pump had to be installed on the carriers used in 1988 and 1989, along with a few minor modifications to their hydraulic systems. However, this task was relatively simple as auxiliary pump mounts are found on most forestry machines, and field mechanics are generally proficient in such work.

As such, the installation times still compared favourably with conventional installations which require between 10 to 16 hours (not including fabrication time for a protective housing). Moreover, the air conditioner was ready to start once the installation was completed. On conventional units, a specialized tradesperson is needed to pump down the system and fill it with refrigerant gas once the compressor and air conditioner are installed.

Cooling Capacity

In all of the tests performed, the capacity of the prototypes met the cooling requirements of the cab. However, the heat load added to the carrier hydraulic system was a problem on the grader used in 1987. This problem was corrected in subsequent trials by installing a dedicated pump for the air conditioner.

Reliability

Mechanical reliability was not satisfactory at first, but improved over the course of the development process. The process control problems experienced in 1987 brought about a change of approach from a fully-mechanical system to a hybrid system incorporating hydraulics and industrial-grade electrical process-control components. The validity of this concept was proven during the trial of the third prototype.

Audible Noise

Noise was a problem only in the second prototype. It was corrected by using acoustic insulation, slower fans, and by stabilizing the housing walls. Additional improvements could be made by using rubber hoses instead of hydraulic piping within the air conditioner. This would dampen the transmission of noise between the hydraulic oil and surrounding air.

Service

Because of the short duration of the trials, it was difficult to evaluate the ease of maintenance of the prototypes. The only major repair occurred when the fans on the 1989 prototype were replaced. This required the removal of the compressor and hydraulic-motor mounting bracket. The air conditioner also had to be purged of refrigerant gas. While the component layout did not hinder this task, the refrigerant pipes should be routed more conveniently in future to avoid purging the system every time the drive belt or the fans are repaired.

Conclusion

The development of a self-contained hydraulic air conditioner designed to meet the needs of the forest industry spanned a period of three years. During the course of its development, the concept went from a fully-mechanical system to an electric-hydraulic hybrid design. With this design, it should be possible to produce a commercial system without exceeding the maximum projected selling price of $4500. The unit's good cooling capacity and projected reliability, coupled with the quick installation time and the minimal know-how required to install and maintain this air conditioner, remain its most attractive features. In the event of a breakdown, a simple mounting system enables owners to remove the air conditioner themselves and bring it to a repair shop, thus avoiding the high costs of field repairs by specialized technicians.

The last prototype proved the concept and can be considered as a pre-production model. Only minor esthetic and ergonomic modifications are needed before commercialization. A better means to control the flow-divider and a more practical control panel are also recommended.

FERIC has thus fulfilled its mandate in this project and future commercialization is left to I&M Electric Rebuilders. Anyone interested in commercializing or acquiring this system, should contact I&M Electric Rebuilders directly at the following address:

Mr. R. Barr
I&M Electric Rebuilders
580 B Squier St.
Thunder Bay, Ontario
P7B 4A8
Tel.: 807-345-3151

Disclaimer

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