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MECHANICAL DRIVE AND CONTROL SYSTEM FOR HIGH EFFICIENCY WET HELIUM EXPANSION ENGINE

PREPARED UNDER FERMILAB SUBCONTRACT NO. 94199
BY CRYOGENIC CONSULTANTS, INC.
ALLENTOWN, PA.

FOR

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1. INTRODUCTION:

CCI Report No. 390-113 entitled, "Wet Expansion Engine for Helium Refrigeration Application", describes a concept of a high efficiency expansion engine capable of operating under varying operating conditions.

A feasibility study of the mechanical aspect for such an engine was made. Simplicity, economy, versatility, reliability, and ease of adjustments were established as design criteria with additional emphasis placed upon using standard commercially available components, where possible.

The purpose of this report is to describe a proposed mechanical drive and sequencing control system developed for this engine.

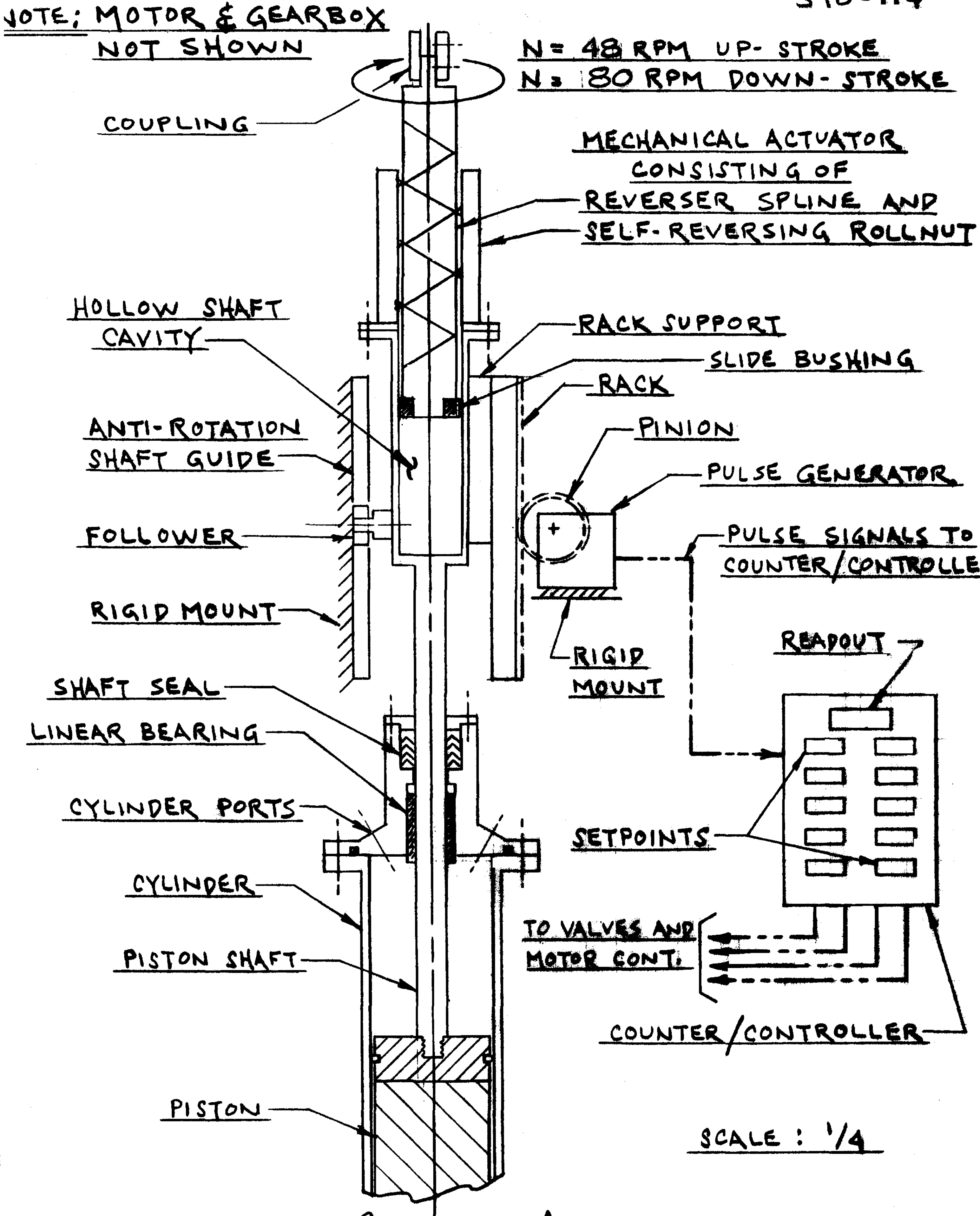
2. DESCRIPTION OF DRIVE:

The mechanical drive is essentially as shown in Figure 1. Rotary motion from an electric motor and gear reducer is converted to alternating reciprocating motion by means of a "NORCO" mechanical actuator. The "NORCO" nut is attached directly to the piston shaft. The shaft, hollowed to accept the "NORCO" screw, is attached to the piston.

Because the pressure is continually balanced on both sides of the piston, the force differential is due only to the shaft area on the drive side and the small differential pressure which may exist. Preliminary calculations show that a 3/4 h.p. motor is sufficient to drive the piston.

Synchronization and valve actuation is controlled by an electronic counter with predetermined count-level controllers. A pulse generator provides a given number of counts per stroke.

Variable piston speed is obtained by equipping the DC motor with a speed controller and remote speed control potentiometers. Synchronizing the speed with the stroke is accomplished by the electronic counter/controller.



DRIVE AND CONTROL ARRANGEMENT
WET EXPANSION ENGINE
FIG. 1

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A more detailed description of the drive is presented in the following paragraphs:

2.1 Motor and Gear Reducer:

The drive selected for this application consists of a flanged worm gear drive with a direct coupled shunt-wound 3/4 h.p. DC motor. The input (motor) speed can be varied through a speed controller over a 30:1 range. The vertical output shaft is rated at 275 in-lbs torque and 400 lb thrust load. The output shaft speed range is 3 to 87.5 RPM.

2.2 Motion Convertor:

Rotating motion is converted to reciprocating motion by means of a "NORCO" mechanical actuator. A double-cut spline causes the "Rollnut" to automatically reverse when it reaches the end of travel without the need of reversing the direction of the input motor. The spline is also available with a 180° dwell (or delay) before reversing at the end of the stroke.

2.3 Shaft:

The hardened steel shaft consists of two sections. The hollow portion attaches to the "Rollnut" and provides a cavity for the actuator spline. In addition, a bearing surface can be attached to the spline which rides within the shaft inside diameter and gives support to the assembly. The remainder of the shaft is of solid construction and is attached to the piston.

2.4 Seal:

The shaft seal is intended to be commercially available chevron-type seals which offer low friction, low leakage rates, and long wear life.

2.5 Bearing:

The side thrust on the shaft bearing is practically nil, and the shaft travel is relatively low.

$$\text{Max. Vel.} = \frac{8.0 \text{ in.}}{5.0 \text{ sec}} = 96 \text{ in./min}$$

$$= 8 \text{ ft/min}$$

Because of such a low velocity and load, it is possible to use a low-cost solid linear bearing, such as an "LM76". This selection also reduces the height of the bearing and seal housing to a minimum.

2.6 Anti-Rotation Guide:

There is always a slight amount of friction between the "NORCO" spline and "Rollnut"; therefore, a sliding guide must be provided to prevent rotation of the shaft assembly.

2.7 Valve Actuation:

The proposed valve actuation system is basically the heart of the unit, replacing the cams, rocker arms, valve tappets, and valve assemblies of conventional reciprocating engines.

The system consists of essentially five discrete parts:

a) Position indicator.

b) Pulse signal generator.

c) Electronic counter/controller.

d) Solenoid valves.

e) Motor speed controller.

The function of each part is individually described:

2.7.1 Position Indicator:

It is necessary to correlate both the solenoid valve actuation and the motor speed to the position and direction of travel of the piston. Several methods exist to accomplish this, but the one selected incorporates a fine-tooth rack and pinion. The rack is rigidly attached to the piston shaft, and the number of teeth would be selected to produce the correct number of revolutions of a spur gear directly coupled to a pulse generator.

The reciprocating shaft and rack drives the pinion through the same number of revolutions each stroke. These revolutions can be converted into pulses by a pulse generator.

2.7.2 Pulse Signal Generator:

Rotating pulse signal generators are available with a wide variety of output pulses per revolution. By choosing various combinations of pulses per revolution with number of gear teeth, each stroke can be divided into an almost unlimited number of increments. Two choices appear at the moment to be convenient.

The first choice is to divide the total stroke into 360 counts representing 360 degrees rotation of the crank of a conventional engine. During the expansion stroke, the number of counts (degrees) per second would be:

$$\frac{180 \text{ counts}}{5 \text{ sec}} = 36 \text{ counts/sec}$$

The piston travel would be 0.0444 in. per count of 0.02778 sec duration (1.600 in./sec).

During the exhaust stroke, the number of counts (degrees) per second would be:

$$\frac{180 \text{ counts}}{3 \text{ sec}} = 60 \text{ counts/sec}$$

The piston travel would be 0.0444 in. per count of 0.01667 sec duration (2.667 in./sec).

The second option, which has special merit because of the nature of this engine, is to divide the total stroke into 200 increments, each representing 1/2% of the total cycle.

During the expansion stroke, the number of counts per second would be:

$$\frac{100 \text{ counts}}{5 \text{ sec}} = 20 \text{ counts/sec}$$

The piston travel would be 0.0800 in. per count of .0500 sec duration (1.600 in./sec).

During the exhaust stroke, the number of counts per second would be:

$$\frac{100 \text{ counts}}{3 \text{ sec}} = 33.333 \text{ counts/sec}$$

The piston travel would be 0.0800 in. per count of .0300 sec duration (2.667 in./sec).

The required range of pulses per second is well within the capability of pulse generators currently on the market.

2.7.3 Electronic Counter/Controller:

The controlling element of the entire system is an electronic counter with approximately six levels of predetermined count/controllers combined with approximately four relay outputs.

To operate this system, first the six input set points are preset at the count level at which a function must occur. The pulse generator registers counts on the readout during the stroke, and as the preset levels are reached, the proper relays are energized (or de-energized) as required. The amount of preset levels and output relays depends largely upon the degree of versatility desired. Advantages of such a system are many:

2.7.3.1 Versatility:

Sequence changes or timing changes can be done instantaneously by changing set points. This eliminates the need to adjust or recut cams as on conventional engines.

2.7.3.2 Self-Policing:

Failure of the counter to reach the reset value of 0 after 8 sec can be programmed to sound an alarm and shut down the engine.

2.7.3.3 Alarm System:

If the pulse generator becomes unsynchronized with the piston stroke, a preset greater than 360 (or 100 as the case may be) or less than zero can trigger an alarm and shut down the system.

2.7.3.4 Cycle Counter:

One preset level can energize an electro/mechanical counter to record the total strokes attained for the record.

2.7.3.5 Precision:

Sequential timing can be preset with accuracy to within 0.045 in. of piston travel with the total stroke subdivided into 360 intervals. Accuracy of timing would be within 0.08 in. of piston travel if the total stroke were subdivided into 200 (1/2%) intervals.

2.7.4 Solenoid Valves:

The cold helium valves are equipped with solenoid operators and, being remote, are mounted in the cold box at points convenient to the engine. The warm solenoid valve is also located at a convenient point.

2.7.5 Motor Speed Controller:

The variable speed drive, 1.600 in./sec for the expansion stroke versus 2.667 in./sec for the exhaust stroke, is obtained by a DC speed controller with two remote speed controller potentiometers. The motor speed for each control pot is preset, then the desired motor speed is governed by sequencing the proper speed control pot into the circuit by relays energized by the controller presets.

More sophisticated speed control can be achieved by adding additional speed pots, relays, and preset levels.

3. SEQUENCING OF FUNCTIONS:

Like all reciprocating expansion engines, it is important that all functions are properly sequenced for proper operations.

An illustrative example of possible settings of the controller presets and their respective functions is presented in Table I:

TABLE I

Set Point	Setting Valve	Function
1	1°	(a) Inlet Valve (V1) Opens (b) Helium Valve (V3) Opens
2	5°	Helium Valve (V3) Closes
3	135 - 155°	Inlet Valve (V1) Closes
4	180°	(a) Exhaust Valve (V2) Opens (b) Motor speed increases to 1,600 RPM to drive piston at 160 in./min
5	359°	(a) Exhaust Valve (V2) Closes (b) Motor speed decreases to 960 RPM to drive piston at 96 in./min
6	360°	(a) Pulse a delay timer which signals alarm if full stroke is not reached. (b) Resets counter to zero.
7	365°	Sounds alarm signifying that counter is unsynchronized

It was assumed in the foregoing example that 0° represents the count when the piston was at the bottom of stroke, and all the settings were based upon 360 counts (or 360°) in one full cycle.

4. CONCLUSION:

A feasibility study indicated that it is possible to construct a drive mechanism and control system to operate a variable speed high efficiency expansion engine utilizing readily available components.

This report describes the components selected for a fundamental engine. It must be remembered that the final degree of control and versatility for any given engine size is limited by the number of controller presets and output relays. It is advisable that an experimental engine incorporate additional presets and relays which then are available if deemed necessary.

Production units can be simplified to suit particular needs. For example, the NORCO" splines are available with multiple pitches which could eliminate the need for a multi-speed motor. If a 2:1 speed reduction is acceptable, the drive motor could be replaced with a simple two-speed AC motor. Also, after the operating parameters are established, it is possible to use a single-purpose controller with a minimum of presets to minimize cost.