1992

Labyrinth Piston Compressors for Low Temperature

H. Meier
Sulzer-Burckhardt Engineering Works Ltd.; Switzerland

Meier, H., "Labyrinth Piston Compressors for Low Temperature" (1992). *International Compressor Engineering Conference.* Paper 858.
https://docs.lib.purdue.edu/icec/858

LABYRINTH PISTON COMPRESSORS FOR LOW TEMPERATURE ACCPLICATION

by

H. Meier
Sulzer-Burckhardt Engineering Works Ltd.
Switzerland

ABSTRACT

The transportation of large quantities of Natural Gas from the producer to the consumer can be achieved either by gas pipeline or in a liquefied state, by ship (LNG tankers). A big part of the LNG destined to the Far East - one of the most active consumer areas in the world - is produced in the Persian Gulf and in Indonesia and is transported to terminals in Japan, Taiwan or Korea. Huge installations must be available for safe and economic handling of the LNG and the associated boil-off gases during storage, loading and unloading at such terminals. Their technical features as well as those on board of the LNG tankers are fascinating in terms both of dimensions and of the art of engineering (Fig. 1).

Safe and environment-conscious handling of the cargo, prevention of leaks, as well as exposure of materials to cryogenic temperatures or rapid temperature changes, are of high concern to the designers.

Among the rotating equipment used in this field are reciprocating compressors. The paper hereafter presents the design features of a Labyrinth Piston Compressor specially designed for LNG boil-off gas in a land terminal.

INTRODUCTION

An LNG boil-off compressor has to cope with a variety of basic physical problems for which a product designed to normal standards would be inadequate. We would like to mention two aspects which are of special interest in this context.

Exposure To Cryogenic Temperatures

LNG at barometric pressure boils off at minus 160 °C. This temperature is well below the limit where some of the common engineering materials alter their properties. As an example we mention the loss of ductility of most unalloyed carbon steels within a temperature span from 0 °C to about - 50 °C [1] . Fig. 2 shows the modes of impact transitions of C-steels and of Ni-alloyed nodular iron.

Bone Dry Gas

Natural gas in form of boil-off is virtually free of water vapour as the dew point is as low as - 160° C. On the one side it is a matter of experience that moisture in a tribological system is an important parameter. Together with a number of other factors it has a distinct bearing on wear rates under non-lubricated conditions. On the other side the phenomenon is not entirely understood in view of its complexity [2] . We therefore refer to tests which have been published [3] and which demonstrate the existence of this problem. Reference is made to Fig. 3 showing wear rates in function of dew points in CH4 in a pin-disc test machine. The tests were made with typical materials used for piston rings and components of stuffing boxes for rotating or oscillating shafts in oilfree compressors.

DESIGN AND MATERIAL SELECTION OF PISTONS AND CYLINDERS

The problems outlined above constituted a good reason to decide for the installations of a labyrinth piston compressor for the handling LNG boil-off gas in a gas terminal in the Middle East as far back as 1985. The running time of this machine now approaches 50'000 hrs representing a valuable record of excellent experience in industrial operation.

The process data which had served for the lay-out of this compressor are presented below:

gas	CH4 98 % + N_2 2 %	
suction 1st	1,036 bar	- 90 to - 160 °C
discharge 1st	5,2 "	+ 25 to - 53 °C
suction 2nd	5,2 "	+ 25 to - 53 °C
discharge 2nd	13,6 "	+ 38 to + 102 °C
suction 3rd	13,6 "	+ 38 to + 48 °C
discharge 3rd	23,4 "	+ 88 to + 160 °C

Material Selection For Cylinders And Pistons

The above data were guidelines for the materials selected for cylinders, labyrinth pistons (Fig. 4) and other components of the machine, of which a sectional view is presented (Fig. 5). The absence of tribological restrictions by using labyrinth sealing techniques left complete freedom for the choice of the best suited metals for the key components in each individual stage. For the 1st stage cylinders with exposure to the lowest temperatures this resulted in the choice of GGG Ni35. This is a nodular cast iron containing 35 % of Nickel, also known under the trade name of Ni Resist D5. This alloy simultaneously exhibits remarkable ductility at low temperatures and one of the lowest thermal expansion coefficients known in metals (Fig. 6). The corresponding pistons were made of cast iron with laminar graphite which was alloyed with Nickel as well.

Reference is made to Table 1 from where the outstanding thermal shock behaviour of GGG Ni 35 in relation to other candidate materials can be seen. This is another valuable virtue specially under transient temperature conditions. The less severe temperatures in the 2nd stage allowed the use of a ferritic nodular cast iron with good fracture toughness down to - 100 °C and bronze for the piston. The 3rd stage cylinder consists of normal cast iron grade GG 20.

CONTROL OF TEMPERATURE AND DEFORMATION OF THE CRANKCASE

Governed by the low gas temperatures the 1st stage cylinders maintain their mean temperature at a level which does not allow the removal of heat to be dissipated to the environment. Therefore they do not have cooling jackets. They cool down well below freezing point of the moisture in the natural atmosphere and consequently become covered with a thick layer of ice when the machine is running. To ensure a good alignment of the path of the labyrinth pistons cold deformation of the crankcase underneath the 1st stage cylinders had to be prevented. This was achieved by means of two special water jackets which extend along the upper face of the crankcase. Special measures for the 2nd and 3rd stage cylinders were not needed as they are thermically under control by means of individual cooling jackets. For illustration please refer to Fig. 5.

INTERNAL AND EXTERNAL LEAKAGE

Consistent with the design of the pistons, labyrinth seals were also used between the double acting cylinders and the distance piece at the upper end of the crankcase (Fig 5). Fig. 7 shows details of the labyrinth seals around the piston rods. Each gland has a collector chamber before the lower end of the labyrinths from where the leak gas is internally returned to the suction up-stream of the 1st stage cylinders.

To attain a perfect external tightness of the machine the passage of the crankshaft through the wall of the crankcase was sealed-off by a rotating double sided ring seal immersed in oil. Thus, the entire inside of the frame could be integrated into the gas containing part and could be pressurized at will with either natural gas or an inert gas. In the case presented here it was left at suction pressure level and was filled with natural gas. Fig. 8 shows details of the shaft seal. The entire machine represents therefore one hermetically closed shell with no gas leakage to the environment.

MAINTENANCE REPORT ON A PERIOD OF 45'000 RUNNING HOURS

Pistons (total of 4)	no replacement whatsoever	
Piston rod seals	1st replacement	after 14350 h
	2nd replacement	after 36993 h
Piston rods	no replacement whatsoever	
Crankshaft seal	1st replacement	after 14350 h
	2nd replacement	after 36993 h
Bearings		
Piston rod guide bearings	1st replacement	after 36993 h
Crossheads	no replacements	
Crosshead pin bearings	"	
Connecting rod bearings	"	
Crankshaft bearings	one bearing lost	after 14350 h
Valves		

No precise records are availvable on life-time of valve discs. However, orders for replacement parts indicate an average life expectation of a valve plate of 9000 hrs at least with no distinction as to cold or warm running valves.

That these results are remarkable will be widely acknowledged.

OUTLOOK

The successful performance of a labyrinth piston compressor in this market segment has encouraged other terminals to install new machines of the same kind built to the same principles. Fig. 9 shows a group of machines in a Taiwanese terminal where LNG is received, stored and evaporated for distribution by a pipeline system throughout the island of Taiwan. The machines have only recently taken up service. The total running time had reached about 5000 hrs for each unit by the end of March '92.

Fig. 10 shows an incoming LNG tanker at the terminal in Taiwan.

CONCLUSIONS

Low gas temperature constitutes a difficulty to gas compressors in two ways: physical contact with cold gas and consequences for material properties, and: absence of humidity (low dew point) with a strong bearing on tribology in non-lubricated areas. The application of labyrinth sealings in reciprocating compressors is a logical answer to this problem. Labyrinth piston compressors have demonstrated this in industrial operation successfully down to the boil-off temperature of natural gas at minus 160 °C. Such machines can be built with zero leakage to the environments. They need little maintenance.

REFERENCES

[1] Rinebolt, J.A.: Harris, J.W.: Trans. Amer. Soc. Metals 43 (1951) P. 1175 - 1214.

[2] Feistel N. Sulzer-Burckhardt Ltd.
Tribology and Wear in dry running Piston Compressors, a complex Problem.
Proceedings Lehrgang 13837 (1991) Techn. Akademie Esslingen.

[3] Schubert R. Einfluss der Gasatmosphäre und deren Wasserdampfgehalt auf den Gleitverschleiss von PTFE Komp.
(Linde-Berichte aus Technik und Wissenschaft 29/1971)
Trans. of the ASME, Journal of Lubrication Technology 1971.

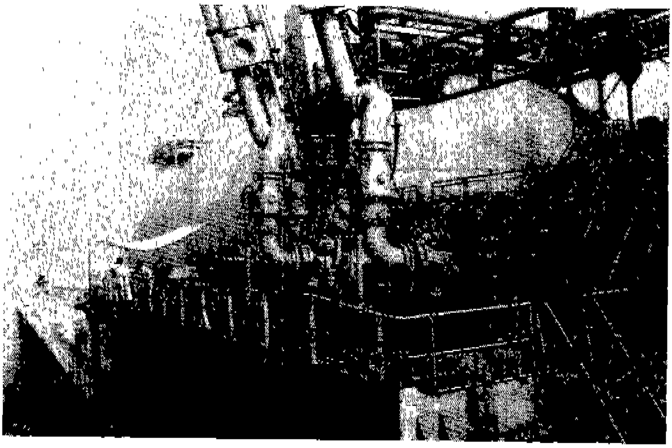

Fig. 1: Unloading of LNG on Board of LNG Tanker.

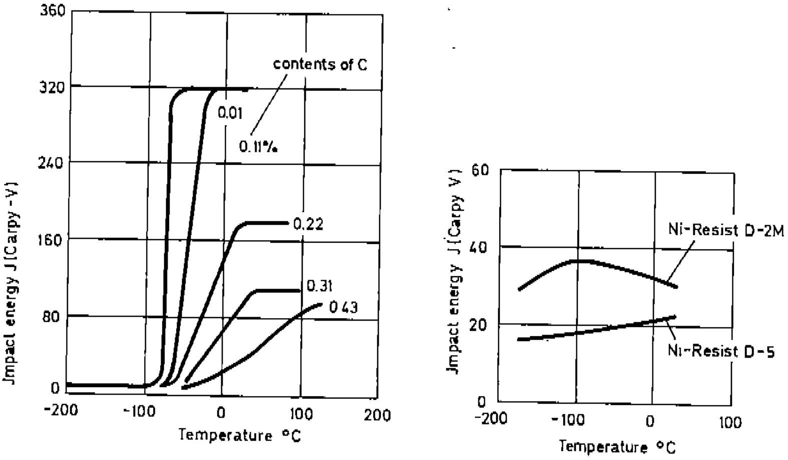

Fig. 2: Transitions of Impact Energies of non alloyed C-Steels and Ni-alloyed Nodular Iron ("Ni Resist").

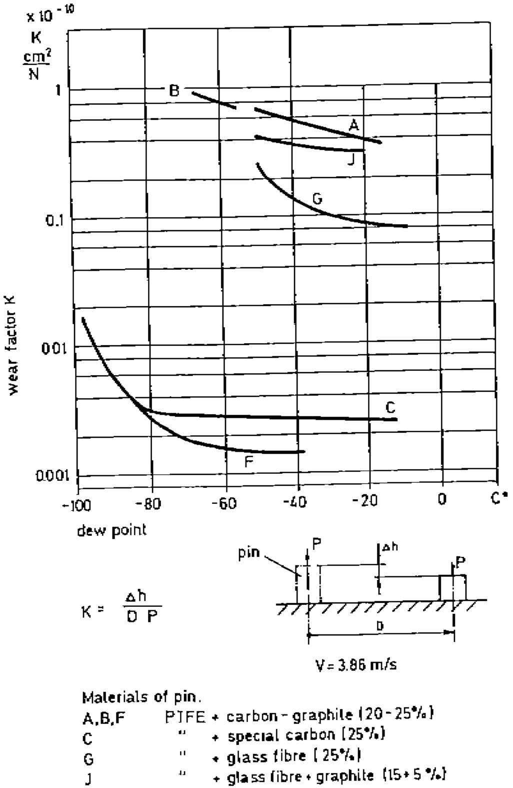

Fig. 3: Wear Rates measured in a Pin-Disc Test of PTFE Samples in Methane [3] .

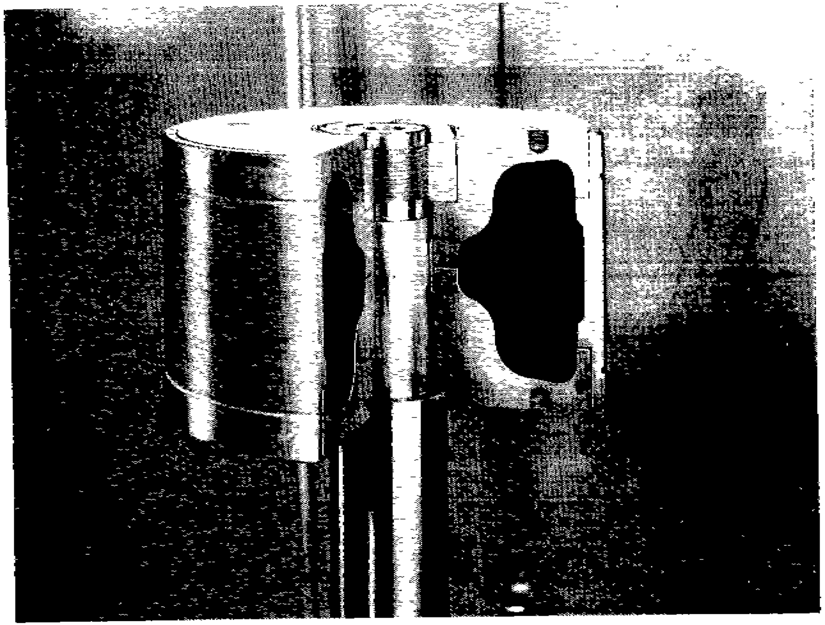

Fig. 4: Cut-away View of a double acting Labyrinth Piston.

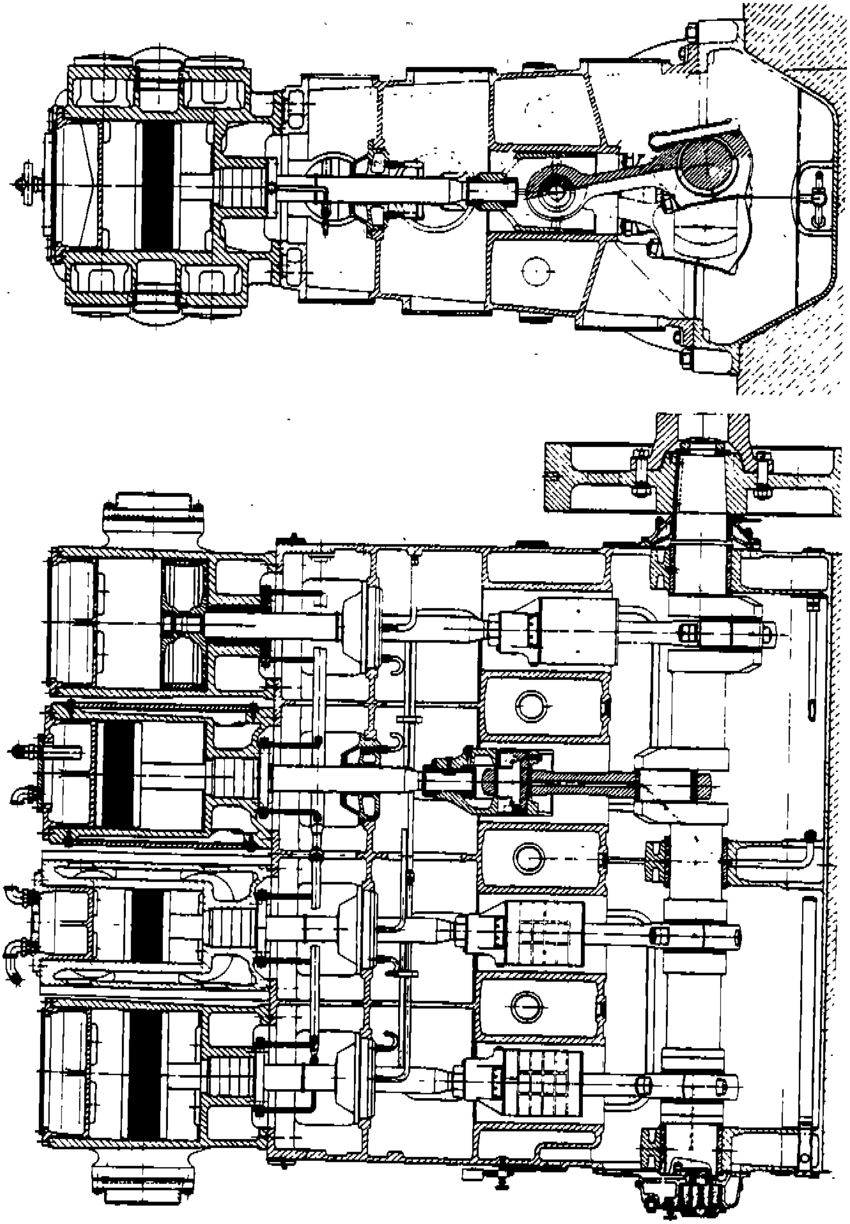

Fig. 5: Labyrinth-Piston Compressor for LNG boil-off.
4 double acting cylinders, 3 compression stages.
Closed crankcasing. Suction temp. - 160 °C .

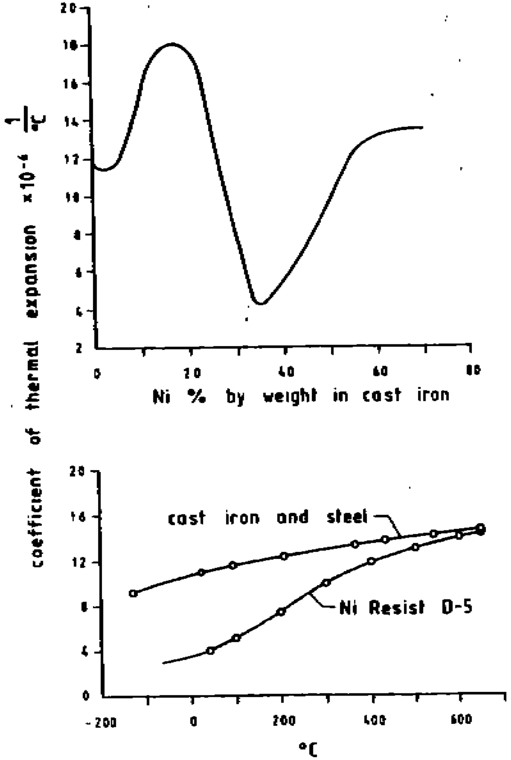

Fig. 6: Coefficient of Thermal Expansion for Cast Iron and Steel in function of % Ni and Temperature.

	Tensile strength ③ N/mm²	Endurance limit ① N/mm²	Youngs modulus N/mm²	Thermal expansion coefficient 10^{-6}/°C	Thermal shock stress ② N/mm² (Δt=100°C)	Ratio ②/①	Ratio ②/③
Cast iron GG 18	180	80	85000	11,7	100	1,25	0,55
Austenitic steel Cr Ni	460 ⋮ 600	230 ⋮ 300	204000	20	410	1,8 ⋮ 1,4	0,89
GGG Ni Cr 20 2 Type D 2	430	190	125000	17,6	220	1,1	0,51
GGG Ni 35 Type D 5	410	185	127000	4,5	58	0,32	0,14

Table 1: Candidate Materials for low Temperature Components. Comparative combined properties.

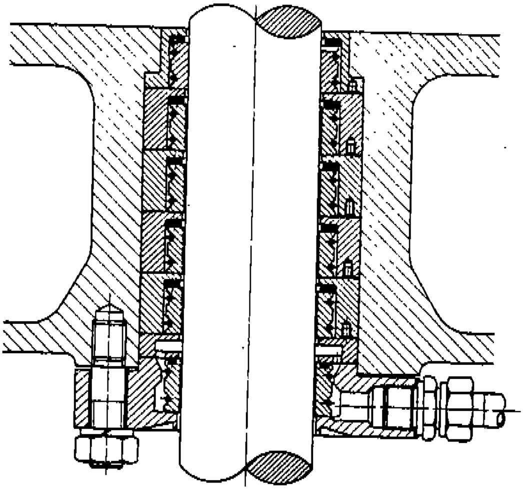

Fig. 7: Internal Labyrinth Sealing between double acting Cylinder and Distancepiece of Crankcasing (Piston rod sealing).

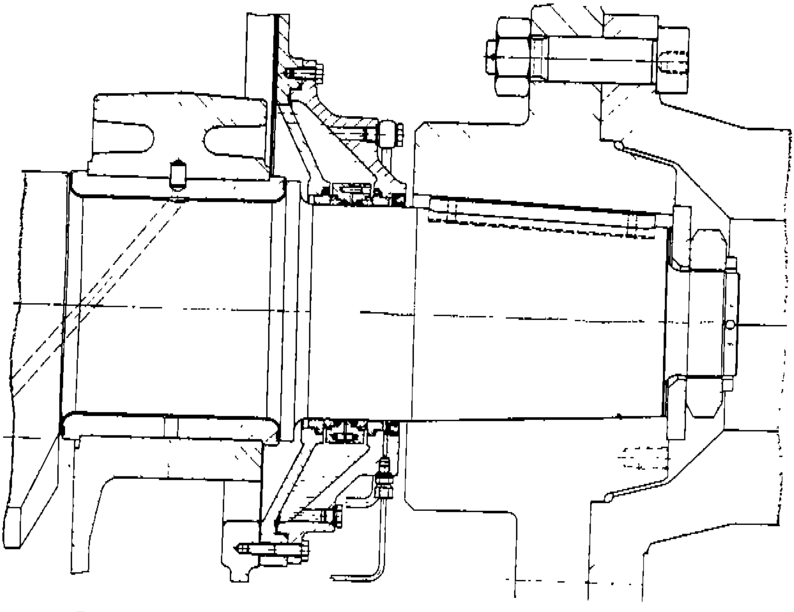

Fig. 8: Gas-tight sealing of Crankshaft between Crankcasing and Environments.

Fig. 9: Group of 3 Labyrinth Piston Compressors for LNG-Boil-off in a Terminal in the Far East.

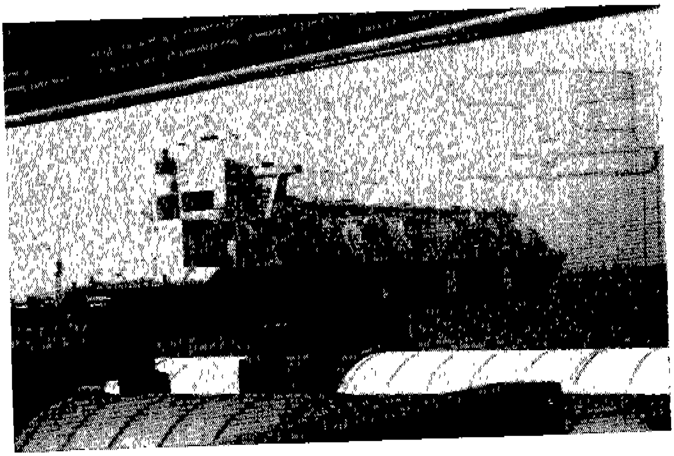

Fig. 10: LNG-Tanker ready for unloading.