MOTORIZED VALVE FOR CRYOGENIC APPLICATIONS IN SPACE LABORATORIES

Frank G. Wiessner

Linde AG Process Engineering and Contracting Division
Dr. Carl-von-Linde-Str. 6-14, D-82049 Hoellriegelskreuth
Telephone: +49/89/7445-3749/Fax: +49/89/74454940
E-mail: Frank.Wiessner@Linde-VA.de

ABSTRACT

In July 1995 ESTEC commissioned LINDE VA to design, build and test a motorized valve for cryogenic applications.
For execution of this contract LINDE cooperated with ETEL, as subcontractor delivering the electrical motor and NORGREN/HERION, supplier of the valve body with the seat/poppet. LINDE constructed and manufactured the gear assembly between motor and valve body and executed the mechanical and cryo tests.
The partners developed, engineered, manufactured a complete new valve which is characterized by :

- seat/poppet made by metal, three seal rings in the seat
- gear box with a worm gear and a cam drive
- motor as an electrical stepper motor .

The valve was tested in a temperature range between 2 – 373 K with Helium leak measurements, it was vibration tested to check the mechanical stability and it was life time tested to prove the long term operability.
The measured leak rates are excellent for a metal/metal seat/poppet construction, but they did not reach the values specified by ESTEC. On the other hand the tightness was not even affected by metallic particles which were circulated through the valve to simulate debris from e.g. the piping.
The developed valve is a compromise between leak tightness / life time / insensitivity against debris. It is considered that a robust, reliable valve with reasonable leak rates with respect to the operation purpose is better than a valve with extremly high tightness but only under ideal conditions and only for a few cycles.

1. BACKGROUND AND REQUIREMENTS

Science missions employing cryostats to cool highly sensitive instrumentation to measure infrared sub-millimeter radiation require a number of shut-off valves for filling, venting and closure of the cryostat which is finally filled with liquid Helium.
The valves configured to be operated only once in space, always have to be operated many times during integration, test and final filling prior to launch. Due to the various preparation works and the final task the valves have to be designed for an extrem temperature range of 373 K down to He II temperature of below 2.17 K.
Once closed, only low leakage rates are allowed in order to make the most efficient use of the stored LHe, maximizing the mission's duration in space. It shall be noted, that the low leakage rates have to be achieved for superfluid helium, even when the valve has been contaminated with solid particles.

Due to the space mission other special requirements have to be fulfilled. They include restricted power budget, weight and dimensions, as well as leak thightness under high acceleration loads and absolute functional reliability (once in space any service or repair is excluded).

2. TECHNOLOGY

The developed valve is a complete new design with respect to the seat/poppet and the gear assembly which transforms the rotating motion of an electrical motor to a linear motion in order to drive the shaft of the valve poppet.

2.1 Design Criteria

Concerning the seat/poppet configuration the basic decision was to use steel also for the seat. This decision was made to keep the tightness even if contaminated fluids are operated and even after 3000 cycles. According to our experience these targets cannot be reached with a soft seat valve.

Concerning the actuation mechanism the basic decision was to use a motor and a gear in order to transform the rotating motion to a axial motion and to amplify the torque of the motor. Such a system ensures a soft drive operation with a low power consumption.
The latch valve is such a system, but it has some functional disadvantages which should be avoided by a principly new designed mechanism.

Moreover the three parts of a valve

- motor
- motion transformer
- valve body with the seat/poppet

should be clearly separated parts. So each part can be developed, tested and improved as a stand alone mechanism.

2.2 Design Results

The motor

The motor is a 24 stepper motor, developed and manufactured by ETEL. It was more or less already available.

The motion transformer

The gear elements are a worm and a worm wheel which provide a high amplification rate of the motor torque and is not backdriveable, that means it keeps its actual position even without energy or additional latch mechanism.

The transformation from the rotating motion to the axial motion, which drives the shaft of the poppet, as well as a second amplification is made by a disc cam which drives a roller. The possibility to design different sections (different radius) allows the production of strokes with a long travel distance but little amplification rate or a short travel distance with a high amplification rate, that means a high driving force to the poppet.

At the beginning the disc has no radius increase at all. So the motor has only to turn the gear parts without producing driving forces. That is helpful to overcome the friction forces during the start phase.

The main friction forces are produced in the two gear elements. Especially by suitable lubrication these forces can be controlled, also for many operations.

Additionally the cam disc actuates the micro switches which indicates that the poppet has reached the end position.

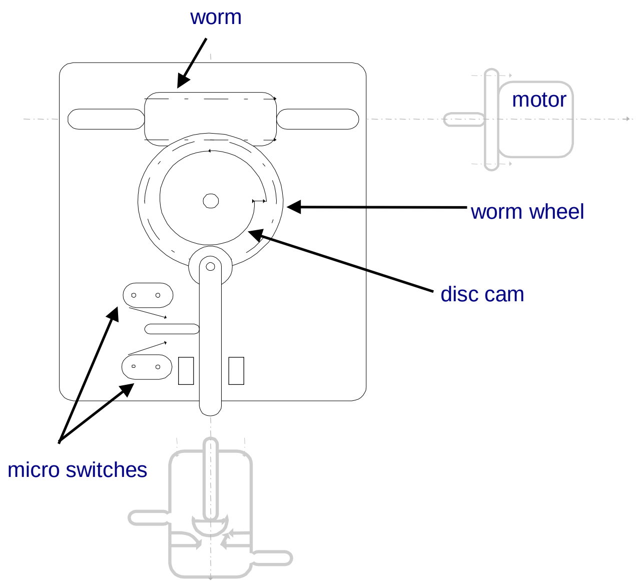

Figure 1: Motion transformer: gear assembly for transforming the motor torque

Valve body

The valve body comprises the seat/poppet and a spring system for the shaft of the poppet.

The seat construction is a new design with three seal rings which are contacted by the poppet with a sperical shape. Both parts are made of steel. This system's advantages are:

- insensitivity against debris in the fluid
- flexibility of the seal rings
- the possibility of the poppet to centre itself.

The spring system provides the force to ensure a defined force to keep the poppet closed independent of the real stroke of the shaft and to drive back the poppet to the open position.

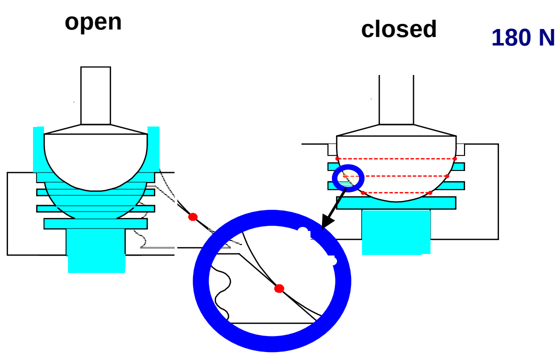

Figure 2: Seat/poppet construction

3. TEST PROCEDURES AND RESULTS

The pretests of the motor, the seat/poppet and the motion transformer were carried out by the responsible companies.

Function tests of the complete valve were executed by LINDE.

3.1 Test Procedures

The tests of the prototype valve carried out at the cryo laboratory of LINDE comprised the following measurements and investigations:

- Function at 100 °C
- Helium leak rate measurements between 20 °C and 2 K
- Helium leak rate measurements after flowing a liquid contaminated with particles through the valve which was several times switched on/off during the operation
- life time test at ambient temperature with 3500 cycles

The mechanical stability tests were executed in the laboratory of DASA and comprised:

- resonance search
- sine vibration
- random vibration
- shock (40 g, half sine)

After these tests the valve was again checked for tightness.

3.2 Test Results

Leak rates

The following data are a summary of many measurements which were not always reproducible, but due to the scope of measurements, it can be noted that these data represent the lower limits; in many cases they were better.

Helium leak rates (mbarl/sec)

temperature (K)	prototype valve
290	2-5x10-5
77	10-4
4.2	1.5x10-3
2	1.5x10-3

The leak rates after the contamination of the seat with particles and after the vibration tests are of the same order.

The inspections after the vibration tests did not show any damage of the valve. The leak rate measurement confirmed this observation.

After all the tests mentioned above the valve was operated with 3500 on/off cycles at ambient temperature without any problem.

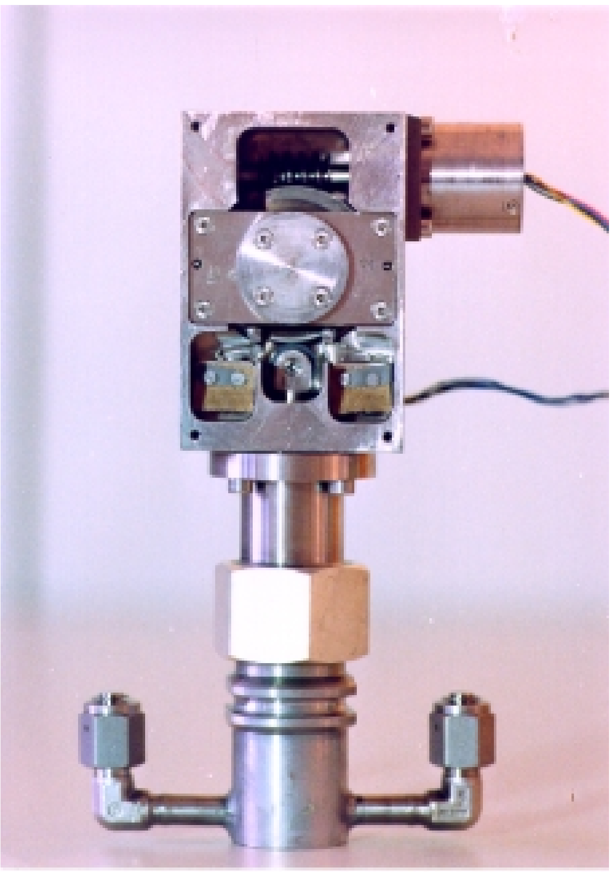

Figure 3: Prototype valve

4. WHATS REACHED

After a long development phase with several unwanted effects, surprises and many experiences with respect e.g. to manufacturing processes or adjustment of the valve parts, it can be finally summarized:

- For a metal/metal seat/poppet valve the leak rates at Helium temperature are excellent.
- Taking into consideration that the leak rates at higher temperatures are not of the same importance, they may be acceptable.
- Due to the metal/metal seat/poppet the tightness is not influenced by contaminations.
- Vibrations and shocks do not influence the tightness and operability.
- The drive mechanism is designed with a safety factor 3 (motor torque/required torque).
- The tests series and the final life tests show the reliable function.
- Extremely low power budget for operating the valve, no power necessary to keep the end position.

After all the development work terminated with a prototype. For a flight model another long way is to go. The main targets will be:

- reduction of weight
- reduction of dimensions
- development of quality assurance procedures.