THE Marquardt COMPANY · VAN NUYS, CALIFORNIA N73 25517

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STUDY OF MULTIPLE CYCLE VALVES

By
H. Wichmann

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THE MARQUARDT COMPANY
Van Nuys, California 91409

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SECTION 1

INTRODUCTION

The purpose of this study was to determine whether valves which can be cycled repeatedly are available from industry for application in the inlet system for the Pioneer Venus Probe Mass Spectrometer. Both solenoid type and latching type valves were considered. In the event no fully capable valves were available from industry, the performance limitations of the available valves were to be determined and the modifications necessary to make these valves fully compatible with the inlet system requirements of the Pioneer Venus Probe Mass Spectrometer were to be established. The study was divided into two principal areas:

Preparation of a valve specification reflecting the requirements of the inlet system cyclic valves for the Pioneer Venus Probe Mass Spectrometer and the submittal of this specification to potential valve suppliers for their response and proposal. Subsequent evaluation and comparison of the proposals received.

Preparation of a design layout of an optimum cyclic valve meeting all of the valve specification requirements.

Results of this study are contained in this report. The study was performed by members of the engineering staff of The Marquardt Company at the Van Nuys, California facility with Mr. H. Wichmann acting as Project Manager. Mr. Louis Polaski was the NASA Technical Project Manager and Mr. William Schmidt the NASA alternate Technical Project Manager.

SECTION 2

SUMMARY

This is the final report of a, "Study of Multiple Cycle Valves", Contract No. NAS 2-7361. The function of the cyclic valves is the sampling of the Venus atmosphere as the space probe descends on a parachute from an altitude of approximately 40 miles to the surface of the planet. Environmental conditions during this descent range from an initial temperature of -75^{o}F and 0.81 PSIA pressure to a surface temperature of 914^{o}F and 1400 PSIA pressure. The principal requirement is that the valves not exceed an internal leakage rate of 0.002 SCC per hour under these environmental conditions.

A detailed engineering procurement specification entitled, "Sampling Valve for the Venus Probe Mass Spectrometer", was prepared to solicit proposals from potential valve suppliers. A total of 17 suppliers were contacted. Results of this survey indicated that no cyclic valves are presently available which fully meet the subject requirements. A design concept which is capable of meeting the requirement and which is based upon a modification of an existing valve design featuring lower temperature capability was submitted by Energy Research and Generation, Inc.. Valves which feature substantially lower temperature capability but which may be suitable for uprating to the Venus Probe requirements are also available from Parker/Beckman and Pyronetics. These valves were originally developed for the Viking Mars Lander.

The most significant developmental problem areas were identified as the meeting of the low leakage requirement at the high temperature and the fabrication of high temperature reliable solenoid windings. A promising alternative to the utilization of high temperature solenoid windings is the utilization of more conventional windings in combination with a thermal resistance element between the valve sealing closure and the valve actuator. Promising all metal sealing closure concepts utilizing a soft metal/hard metal combination which appear suitable for this application have been demonstrated in support of a Jet Propulsion Laboratory program. A design layout of an optimum configuration for the cyclic valve for the Pioneer Venus Probe Mass Spectrometer inlet system was also prepared as a part of this study by The Marquardt Company.

The maximum temperature capability of available valves is approximately 450^{o}F. Utilization of these valves for the Pioneer Venus Probe would permit sampling of the Venus atmosphere down to a altitude of 20 miles or approximately 1/2 of the Venus atmosphere. This approach would constitute a minimum cost approach. However, the temperature data available on the existing valves is limited and before committing to any such approach it is recommended that comparative evaluation tests of the valves manufactured by Energy Research Generation, Inc. and by Parker/Beckman be performed by an independent contractor to confirm the suitability and reliability of these valves. To obtain cyclic valve capability for the entire Venus Probe Mission, will require the expenditure of substantial funds to develop the high temperature and low leakage capability.

SECTION 3

PERFORMANCE REQUIREMENTS

As the name of the study implies, the valves are intended for use as on-off multiple cycle valves in the inlet system of the Pioneer Venus Probe Mass Spectrometer. The Pioneer Venus Mission and experiments are described in Reference (1). Reference (2) presents more details of the atmospheric inlet system for the Pioneer Venus Probe Mass Spectrometer. The actual atmospheric sampling mission is initiated after parachutes have been deployed as the probe enters the Venus atmosphere at an altitude of approximately 40 miles. The exact number of cycles that will be incurred by the valve during the sampling mission has not yet been determined and will be dependent upon selection of the final inlet system and mass spectrometer configuration. However, it appears that a reasonable number of cycles will be approximately 25 during the descent in the Venus atmosphere. In addition a substantial number of ground checkout cycles at ambient temperature conditions will be required.

The temperature and pressure profile of the Venus atmosphere from an altitude of 40 miles to the surface is presented in Figure 3-1. As evident from this figure, the environmental conditions range from an initial temperature of -75^{o}F and initial pressure of 0.81 PSIA to a surface temperature of 914^{o}F and a surface pressure of 1400 PSIA. To prevent the condensation of inlet gases, it is desirable that the sampling valves have the capability of operating over this entire temperature and pressure range.

Since the operating flow rates of the Mass Spectrometer are quite low, it is important that the valve leakage characteristics also be kept very low to prevent possible flooding of the Mass Spectrometer. In discussions with NASA Ames technical personnel, it was determined that the maximum allowable leakage rate through the sampling valves should not exceed approximately 10% of the nominal operating flow rate of the Mass Spectrometer. This corresponds to a maximum allowable leakage rate of 0.002 SCC per hour. This leakage rate was specified to be measured with helium which is a conservative approach since the primary constituents of the Venus atmosphere are carbon dioxide and water vapor which are much heavier gases and which would, therefore, result in leakage rates substantially lower than those observed with helium.

Details of the sampling valve performance requirements are presented in the Marquardt Engineering Procurement Specification No. 402 which is included in this final report as Appendix A. In addition to the severe leakage and temperature requirements the valves also have to be designed to withstand an acceleration of 300 'g's' for 10 seconds. This acceleration occurs during deployment of the parachutes. Since the function of the valves is the sampling of the Venus atmosphere, it was also most important that the materials of construction of the valves were fully compatible with the Venus atmosphere constituents and did not in any way poision the atmospheric samples. Other requirements such as response, power consumption, weight, shock, etc. were of minor importance and can be determined from Appendix A.

VENUS TEMPERATURE AND PRESSURE vs ALTITUDE

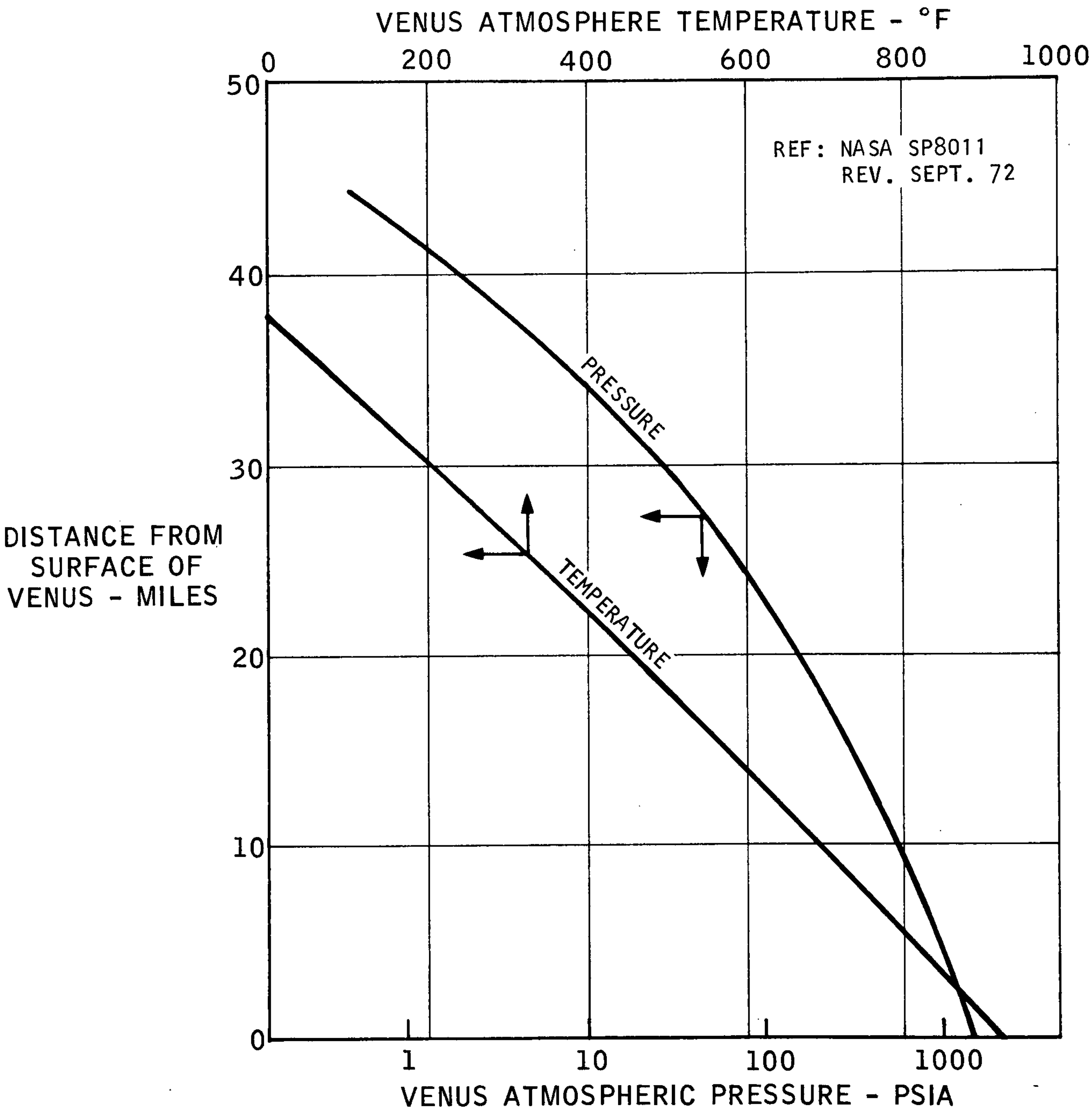


Figure 8-1

SECTION 4

VALVE SURVEY

4.1 VENDOR CONTACTS AND RESPONSES

Marquardt Engineering Procurement Specification No. 402 which is included as Appendix A was submitted to a total of 17 potential valve suppliers to determine if cyclic valves meeting the requirements of the inlet system for the Pioneer Venus Mass Spectrometer are currently available. The procurement specification also stated that in the event that valves are available which generally meet all of the requirements except for the temperature requirement of 914°F these valves were also of interest and that potential means for operating these existing valves to the 914°F temperature should be recommended. The 17 valve suppliers that were asked to propose are listed in Table 4-I.

TABLE 4-I

LIST OF VALVE SUPPLIERS CONTACTED

Energy Research & Generation	Conax
Marotta	Fairchild Hiller
Sterer	Hydraulic Research
Futurecraft	Moog
Eckel	Varian - Vacuum Division
Parker/Beckman	Valcor
Pyronetics	Wright
Varian - Mat	Allen Design
Circle Seal	

Proposals were received from Energy Research and Generation, Inc., Marotta, and Sterer. In addition, technical discussions were held with Futurecraft, Eckel, and Parker/Beckman. Furthermore, to determine users experience with proposed valves, the Jet Propulsion Laboratory, NASA/Langley, and TRW Systems were also contacted.

A summary of the performance characteristics of the valves presently available from or proposed by the five most promising valve suppliers is presented in Table 4-II. It should be noted that the performance characteristics presented therein are based on information supplied directly by these valve vendors as well as by their users. Also the data presented for each supplier is for that configuration which comes the closest to meeting the Pioneer Venus Mass Spectrometer inlet system requirements. Thus, Parker also has available a smaller valve which features the same performance requirements as the Pyronetics valve since it was developed for the same application. Also Energy Research and Generation has developed a valve with performance characteristics comparable to those of the Parker/Beckman configuration. Each of these valve configurations will be briefly described in the following paragraphs.

TABLE 4-II

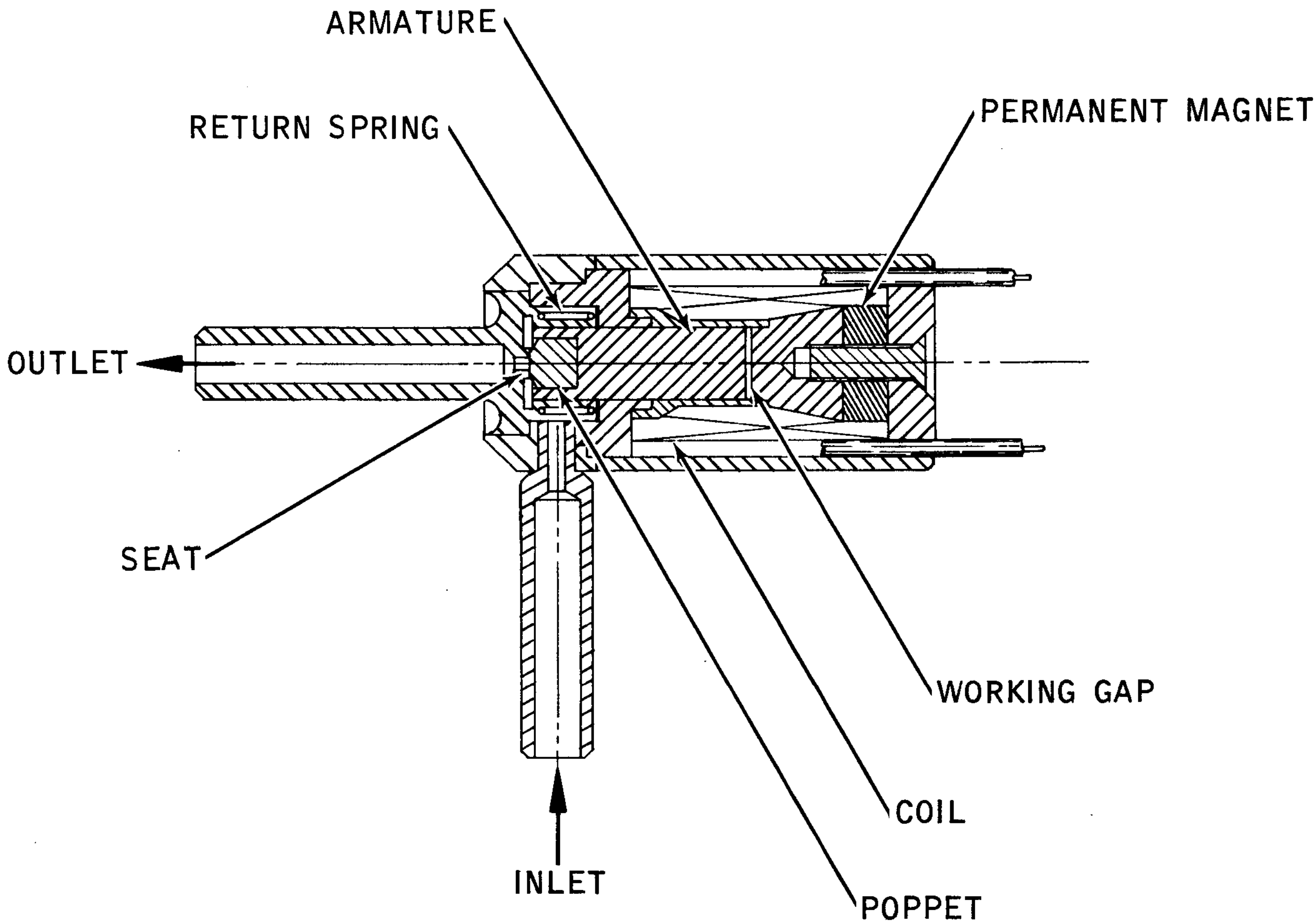
VALVE PERFORMANCE CHARACTERISTICS

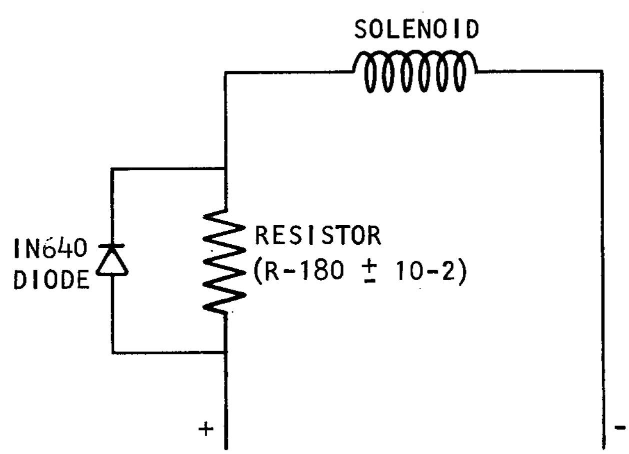
	Pyronetics	ERG	Sterer	Marotta	Parker/Beckman
Maximum Operating Temperature (°F), Actuator	400+	914	500	400	437
Maximum Operating Temperature (°F), Valve	300	914	914	914	437
Leakage @ 15 PSI He (SCC/SEC) 70°F	5×10^{-9}	7×10^{-9}	10^{-4}	No Test Data Available	3×10^{-9}
Leakage @ 1400 PSI He (SCC/SEC) 70°F	(No Data)	7×10^{-8}	No Test Data Available	"	5×10^{-7}
Electrical Power @ 30 VDC & 70°F (Watts)	3	(1.5 amps peak)	5	3.70	(3 amps peak)
Electrical Power @ 30 VDC & 914°F (Watts)	(.5 amps peak)	"	<1	2.15	"
Weight (lbs.)	0.03	0.09	0.75	2.0	0.09
Envelope (Inch Dia. x Inch Long)	3/8 x 1.0	0.56 x 1.0	1-1/4 x 4-3/4	1-1/4 x 4-1/4	3/4 x 1.5
Latching Capability	Yes & No	Yes	No	No	Yes
Materials In Contact with Sample	Stillman SR2702-75 302 Cres Hiperco 50 with Chrome 304 Cres 304L Cres	Gold Plate Prop. #1 Prop. #2 Inco 718 316L SS	Inco 718 347 SS Haynes 6B Haynes 25 Nickel Plate CICO Coat	Gold Plate Inco 300 Series Hastelloy C 17-4 PH	Vespel (40% C) 304L Nickel Plate
Special Requirements	Controller Logic Max P = 500	Separate Tube for Reference Pressure Controller Logic			Controller Logic Purge Tube

The Pyronetics valve is presented in Figure 4-1. In the configuration shown the valve constitutes a latch valve design utilizing magnetic latching forces to hold the valve in the open position and a spring to hold it in the closed position. However, this same valve is also available in a solenoid version (non latching) which is achieved by simply removing the permanent magnet and replacing it with a soft magnetic material. The valve features a sealing closure consisting of a fully trapped Stillmann SR2702-75 compound in the poppet which mates with a raised annulus type 304L crescent seat. Magnetic material utilized in the construction of this valve is vanadium permendur which is chrome plated for compatibility reasons. Other materials of construction coming in contact with the sample are 304 crescent and 302 crescent. Operation of the valves is achieved by energizing the single coil to open the valve. Once the valve has opened, the permanent magnet maintains sufficient magnetic flux in the actuator circuit to hold it in the open position and no electrical holding power is required. To close the valve a signal of inverse polarity to the coil is required which demagnetizes the permanent magnet and permits the spring to return the poppet to the closed position. The number of ampere turns applied to the coil to demagnetize permanent magnet is critical and is controlled by means of the valve drive circuit shown in Figure 4-1. The ampere turns are critical since application of too high a magnetic coercive force (ampere turns) will result in remagnitizing the magnetic in the opposite direction and this in turn will result in opening the valve again and again latching it in the open position. The principal attraction of the Pyronetics valve is its extremely low weight (0.03 lbs.). However, the rather sensitive latching actuator, the temperature limitation of 300°F, and the pressure limitation of 500 PSIA are considered significant disadvantages.

The ERG concept is shown in Figure 4-2. The ERG concept proposed constitutes the most advanced valve design submitted and shows a potential for meeting all the performance requirements of the Venus Mass Spectrometer inlet system. The valve features a latching type actuator which utilizes magnetic latching forces to hold the valve in both the open and closed positions. Details of the actuator construction are considered proprietary by ERG. The sealing closure proposed utilizes a conical interface with differential angles between the poppet and sealing surfaces. A hard metal/soft metal sealing closure interface is employed. Specific materials of construction of the sealing surfaces are considered proprietary by ERG. The number of materials exposed to the gas sample are minimized by employing a gold plated diaphragm between the sealing closure and actuator. To minimize actuation forces the actuator cavity is pressurized through a separate tube with the Venus atmosphere as well. The valve also incorporates an impact absorber to minimize poppet impact forces during the valve closure. This impact absorber is in the form of a compliant metallic element in the valve stem. The valve also features a custom made position indicator for determining valve closed position. The actuator has been made compatible with the 914°F temperature by utilizing either aluminum wire with aluminum oxide insulation or silver wire with nickle oxide insulation. Operation of this valve is achieved by simultaneously signaling two coils in the actuator for approximately 10 milliseconds. To close the valve these same coils are supplied with an inverse polarity signal for the same duration. The primary advantage of the ERG valve is its ability to fully meet the Venus Probe Mass Spectrometer inlet system requirements and to carefully control the materials which are exposed to the gas sample. Potential development problems may arise with the diaphragm and the apparently tight guidance at the poppet shaft required to achieve effective sealing.

PYRONETICS PEANUT VALVE AND WIRING DIAGRAM

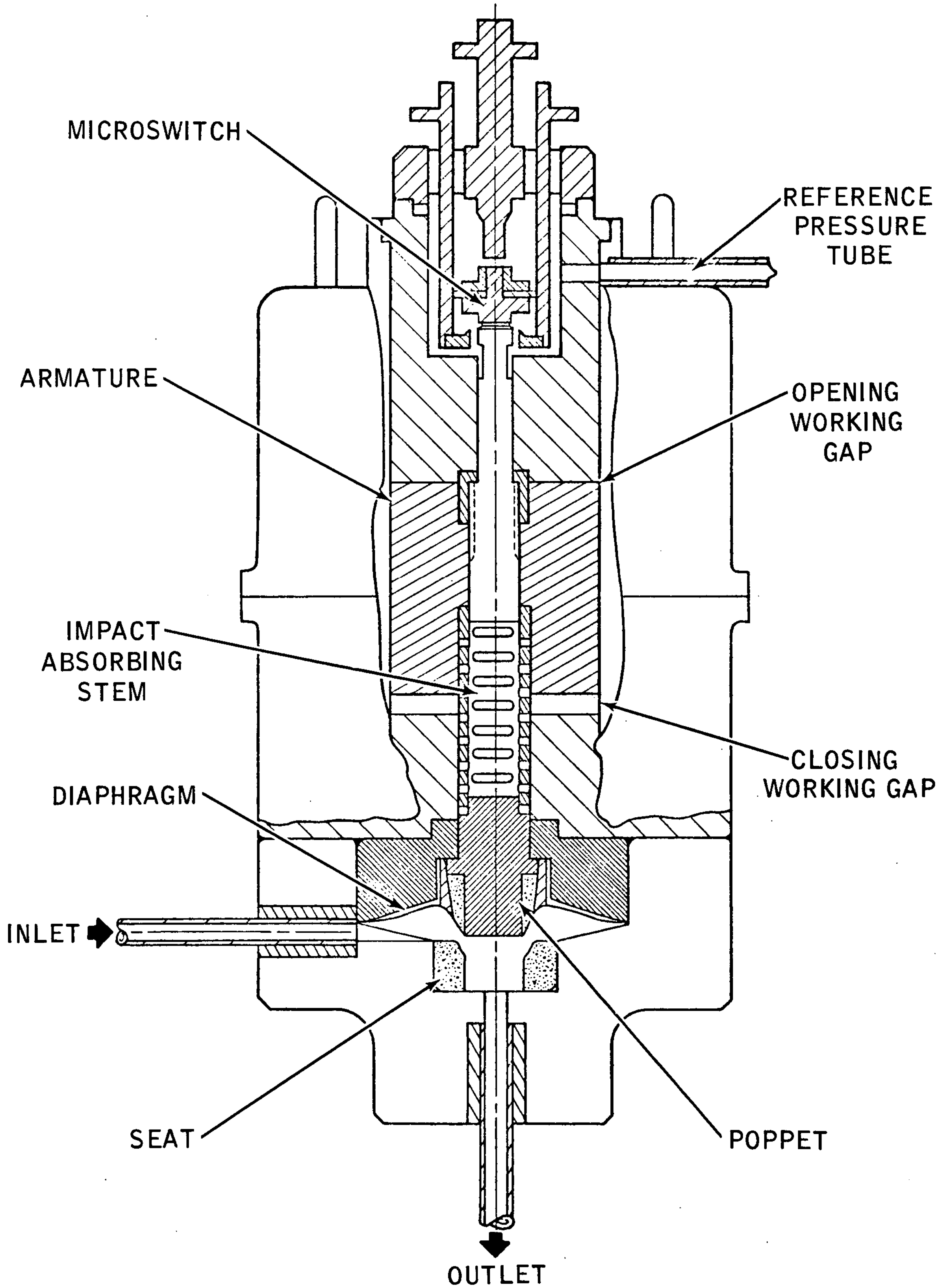




VALVE DRIVE CIRCUIT DIAGRAM
POLARITY INDICATED OPENS VALVE

Figure 4-1

ERG VALVE



Figur[illegible]-2

The valve proposed by Sterer is shown in Figure 4-3. This valve is typical of numerous valves supplied by Sterer to various spacecraft contractors for cold gas attitude control application. It features a ball poppet mating with a sharp edged seat. Materials of construction of the poppet seat are Haynes 6B and Haynes 25. The actuator is of a conventional solenoid construction with a maximum temperature capability of 500^{o}F. Sterer feels that the sealing closure may be operated as high as 914^{o}F without exceeding the 500^{o}F temperature at the actuator. The weight of this particular valve is significantly more than that of the ERG, Pyronetics, and Parker/Beckman valves. However, the greatest problem with the proposed Sterer valve is the fact that Sterer feels that they cannot meet the leakage requirement of 0. 002 SCC per hour and , therefore, the valve is really not suitable in its present configuration for the Pioneer Venus Mass Spectrometer inlet system application.

The valve proposed by Marotta is shown in Figure 4-4. This valve features a conical poppet seat interface with the mating materials made of Hastelloy's C and 17-4PH. The valve is of a simple solenoid configuration requiring power to open and to hold it open and depending upon a coil spring to return it to the closed position. The valve utilizes some existing components and as a result of this is rather heavy. The design approach is indended for sealing closure operation at 914^{o}F while the solenoid coil is kept at 400^{o}F to permit utilization of conventional insulation materials. This temperature is maintained by means of cooling fins which are installed on the housing between the actuator and the sealing closure. Other materials of construction which come in contact with the sample gas are gold plating, inconel, and 300 series stainless steel. The particular sealing closure interface shown in Figure 4-4 has not been previously demonstrated for the low leakage requirements of this specification and will require development according to Marotta technical personnel. Because of the lack of data regarding the capability of the sealing closure to meet the low leakage requirement and because of the rather high weight of this valve configuration, it is not considered a very promising candidate for the Pioneer Venus Mission application.

The valve cross section shown in Figure 4-5 is of the so-called "peanut" valve fabricated by Parker. It is very similar in construction to the Parker/Beckman valve whose performance characteristics are presented in Table 4-II. The principal difference between the "peanut" valve and the Parker/Beckman valve lies in the somewhat larger size of the latter and in the sealing closure interface configuration. The Parker/Beckman valve utilizes a spherical interface mating with a sharp edge 0. 005 inch wide sealing lined. Sealing closure interface stresses are approximately 4000 PSI and materials of construction are polyimide with 40% graphite and 304L. To minimize poisioning of the gas sample, the Parker/Beckman valve also features a bleed in the actuator cavity which bleeds all that gas that has entered the actuator cavity overboard and thereby minimizes the possibly detrimental effects of the nickle plate utilized on the vanadium permendur actuator material. The Parker/Beckman valve has been designated with both company names because Parker originally fabricated the valve and still does; however, the latest configuration has been developed primarily by Beckman with Parker's roll limited to that of hardware supplier.

The Parker/Beckman valve features a latching valve type actuator which utilizes a radially polarized ring magnet to latch the valve in either the open or closed positions. The armature is shuttled from the opened to the closed position and vice versa by energizing two coils so as to establish most of the magnetic flux at the opening gap in order to open the

STERER VALVE

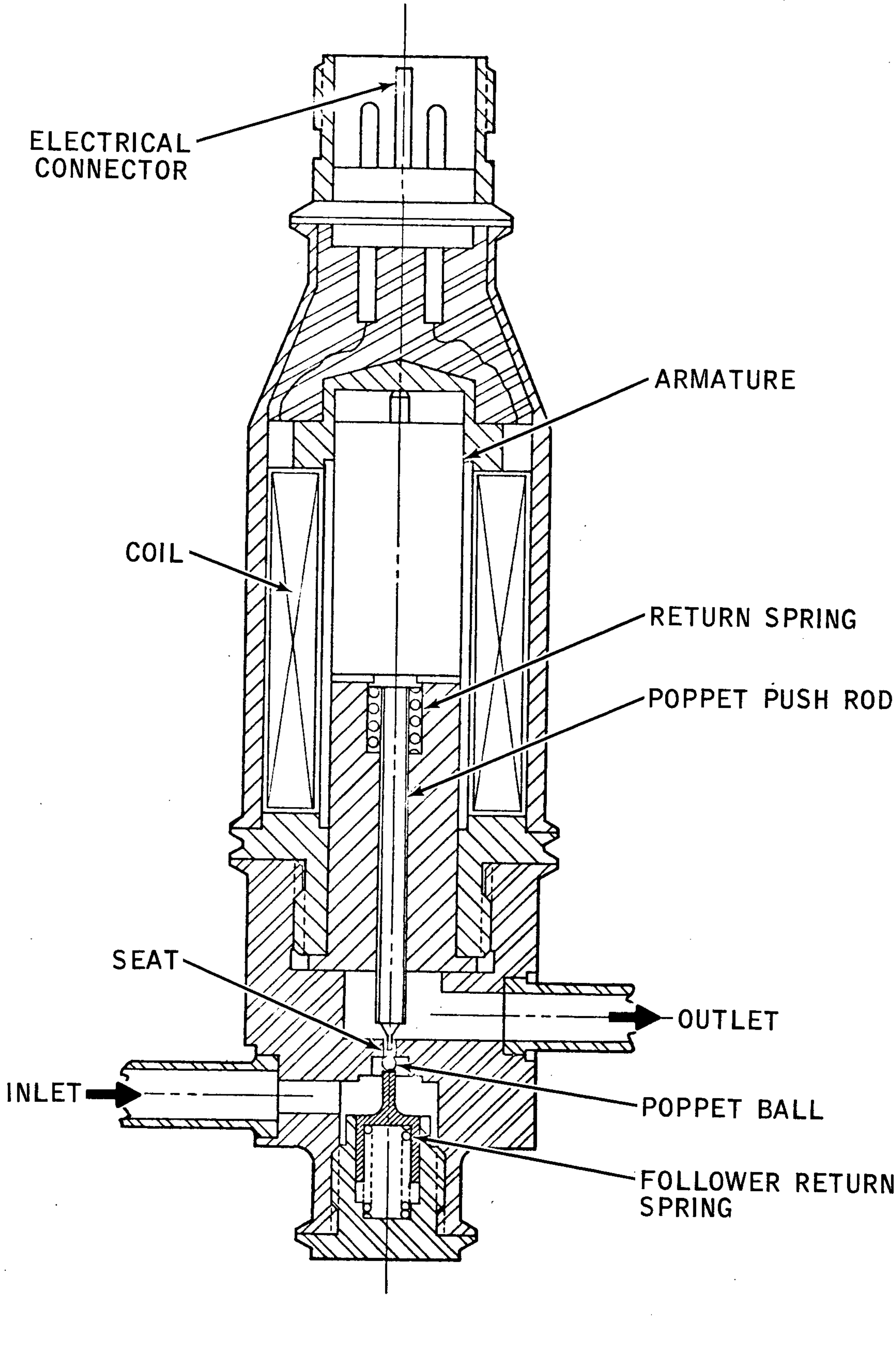
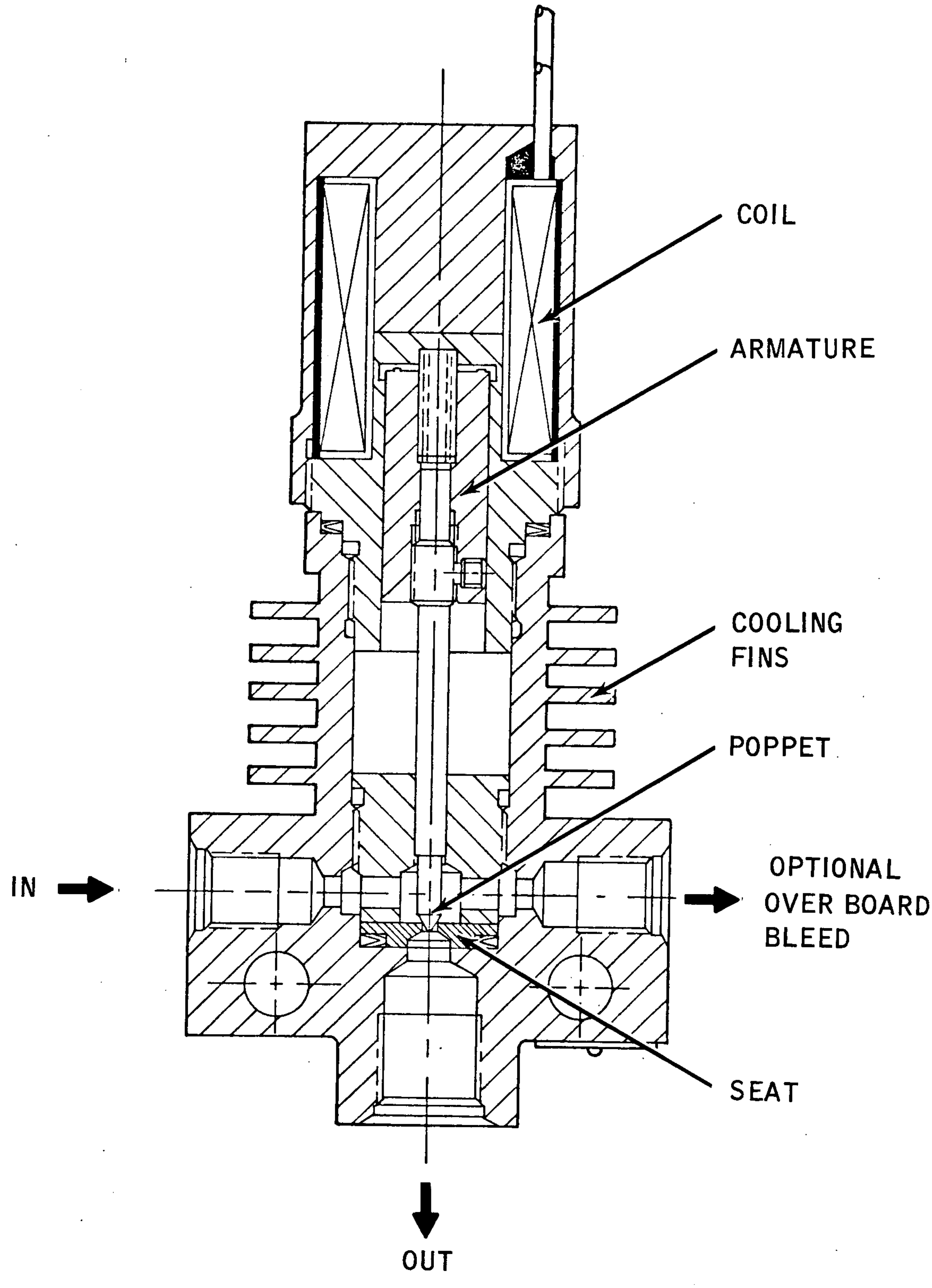


Figure 4-3

MAROTTA VALVE



Figur[illegible]

PARKER "PEANUT" VALVE

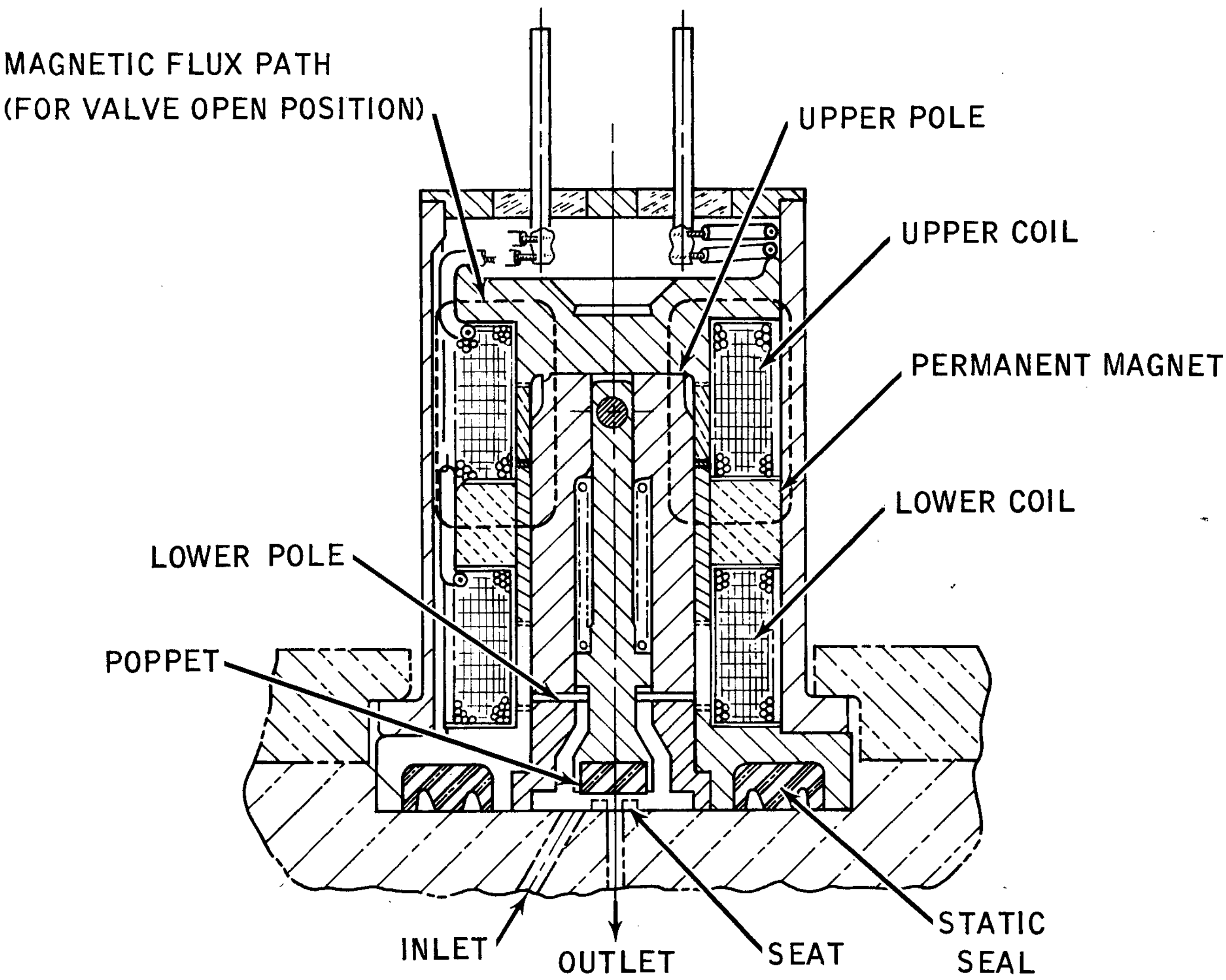


Figure 4-

valve and then by reversing the polarity to these coils to establish most of the magnetic flux at the closing working gap to close the valve. The valve employs copper windings with conventional insulation. The armature is coupled to the poppet through a spring so as to permit simultaneous seating of the armature at the closing pole face as well as of the poppet at the seat. This particular valve has been demonstrated at temperatures up to 437^{o}F and pressures up to 1400 PSIA. Peak current required for shuttling the armature is approximately 3 amps for a period of roughly 10 milliseconds and the weight is 0.09 lbs. As a result of substantial development efforts, the leakage rate of this valve is apparently quite attractive at 5×10^{-7} SCC per second.

In reviewing the performance characteristics of the 5 valves just discussed, it is apparent that the valves proposed by Marotta and Sterer are not of immediate interest. Of the remaining three valves, the concepts available from or proposed by Parker/Beckman and ERG are of most interest. The Parker/Beckman valve is apparently well developed and meets all of the Pioneer Venus Mission requirements except for the maximum temperature requirement. ERG has a valve available with similar characteristics and furthermore proposes to develop a valve which fully meets the Pioneer Venus requirements. By utilizing presently available valves from either ERG or Parker/Beckman sampling of the Venus atmosphere down to an altitude to 20 miles could be accomplished. To obtain complete sampling capability down to the Venus surface development of the design concept proposed by ERG would have to be undertaken.

4.2 SEALING CLOSURE CONCEPT AND MATERIALS

Both of the currently available ERG and Parker/Beckman valves utilize a sealing closure interface consisting of a reasonable hard metal (stainless steel) and Vespel (a DuPont tradename). The particular Vespel utilized by Parker/Beckman includes 40% graphite. The exact Vespel utilized by ERG is considered proprietary by that company. The Parker/Beckman valve employs a 0.005 inch wide sealing land and sealing stresses of 4000 PSI. This corresponds to seating forces of approximately 3 lbs. Impact forces during poppet closure are probably somewhat higher. A well lapped poppet surface is required as well as a number of run in cycles to achieve the proper mating between poppet and seat and to achieve the low leakage characteristics. The spherical interface configuration essentially assures self alignment and the plastic is forgiving enough to permit repeatable low leakage characteristics. Details of the Vespel/metal sealing closure interface used by ERG were not provided by that company.

Utilization of a Vespel in the sealing closure is limited to approximately 570^{o}F since the material outgases at about that temperature. Sealing closures required to operate as high as 914^{o}F will have to be of an all metalic configuration. All metal sealing closure technology has consisted of two approaches. One approach utilizes very hard metal or ceramics in both poppet and seat and achieves low leakage characteristics by providing extremely smooth (1 AA finish or less) and very uniform surfaces (less than 1 helium light band flatness for flat sealing closure interfaces). Relatively low sealing closure interface loads are employed. These types of sealing closures are characterized by extremely high cycle life and reasonably low leakage rates. The other all metal sealing closure approach utilizes a hard metal mating with a soft metal. Typical metals are Type 440C stainless steel, Haynes alloys, Hastelloy C, Inconel 718 or even ceramics for the hard material. The mating surface is then a soft metal such as copper, silver, gold, aluminum, etc. The hard/soft metal sealing closure is then designed to operate above the yield point of the softer material. The hard material is again lapped to a very fine surface finish and this surface is used to deform the softer material to assume the same surface configuration. This approach results in very low leakage seals of the type required for the Pioneer Venus Mass Spectrometer system sampling valve but also features a more limited cycle life. However, cycle lives in the order of 1,000 - 10,000 cycles have been reliably demonstrated with this approach. The exact sealing closure interface loads required for this approach depend upon the particular soft metal chosen as well as on the contact area of the soft metal. In general, the width of the contact area of the soft metal is minimized and is limited only by machining and tolerance considerations. No experimental data relating contact area width with leakage rates is available for the hard/soft metal sealing closure interface configuration.

The fairly high temperature requirement of 914^{o}F effectively eliminates the use of copper because of oxidation problems and also makes aluminum rather undesirable for use as the softer metal in the sealing closure. Because of its ready availability and the fact that it is a noble metal, gold appears to be most suitable for the requirements of this study. Another aspect that must be evaluated in analyzing sealing closure configurations is the guidance techniques employed in mating the poppet with the seat. The better these guidance techniques or in effect the more repeatable the mating of the poppet with the seat is the less critical the surface finish of the hard part of the sealing closure becomes. It has been Marquardt's experience that the most repeatable mating of a poppet with a seat can be achieved by utilizing metalic flexure guidance of the poppet. Furthermore, very fine surface finishes can best be obtained with a flat surfaces or with spherical surfaces as opposed to conical surfaces. Thus it would appear that the most reliable and lowest leakage configuration sealing closure interface should be a flexure guided flat poppet seat interface. Utilization of the nickel plated sliding fit guidance configuration employed in the Parker/Beckman valve in combination with an all metal seal closure is considered a rather marginal approach and is not recommended at this time. The approach proposed by ERG which employs a proprietary lubricant on the sliding guidance surfaces in combination with what appear to be very low clearances is a significant improvement over the Parker/Beckman design. However, the conical differential angle sealing closure interface proposed by ERG is not considered as desirable as a flat interface.

It must be recognized that none of the proposed sealing closures has to date demonstrated the low leakage requirements at the 914^{o}F temperature. Thus considerable development in attaining this capability must be reconed with.

4.3 ACTUATOR CONCEPTS

The survey performed in support of this study included both solenoid and latching type actuators. Proposals for both types of actuators were received although the most promising valve configurations all utilized magnetic latching type actuators. These actuator concepts and their materials of construction are briefly discussed in the following sections.

4.3.1 Magnetically Latching Actuator Concepts

There are basically two types of magnetically latching actuator concepts. These are shown in the valves in Figures 4-1 and 4-5. The concept shown in Figure 4-1 utilizes a single magnetic circuit with a permanent magnet (typically alnico V). This magnetic circuit also features a single working gap. By energizing the coil surrounding the working gap, magnetic flux across the working gap is established to shuttle the armature to the open position and to magnetize the permanent magnet at the same time. The permanent magnet then maintains the magnetic flux in this circuit when the signal to the coil is terminated. This type of latching actuator is latched magnetically only in the open position. To close it, the permanent magnet must be demagnetized and the armature is shuttled back to the closed position and then held in the closed position by means of a coil spring. Demagnetizing the permanent magnet is a fairly critical technique since a coercive force of just sufficient magnitude to demagnetize the magnet without remagnitizing it in the opposite direction must be provided. This demagnetizing magnetic coercive force is applied by reversing the polarity to the driving coil and by operating the coil at a lower current by means of an additional resistance in the driving circuit. Because of the critical demagnetizing operation this latching actuator concept is considered significantly inferior to the other latching actuator concept presented in Figure 4-5 and discussed in the next paragraph.

The magnatic latching type actuator shown in Figure 4-5 employs a radially polarized ring magnetic which is always magnetized and which feeds magnetic flux into the center of the armature. Most of this magnetic flux will then follow the path of least magnetic reluctance which is across the opening working gap in the view shown. As shown relatively little magnetic flux flows across the closed working gap because of the significant air gap that exists at that location. To shuttle the armature from the open position to the closed position, both of the coils surrounding the opening working gap and the closing working gap are energized momentarily in such a direction as to oppose the flux in the opening magnetic circuit and to establish flux in the closing magnetic circuit. The direction of flux through the permanent magnetic remains the same. The magnitude of the magnetizing force provided by the coils is not particularly critical. The worst that could possibly happen was that if the magnetizing force was insufficient the valve simply would not shuttle.

The Marquardt Company has developed a bistable actuator which is identical in configuration to that shown in Figure 4-5. Development of a coaxial valve utilizing this actuator is reported in Reference (3). The only difference in Marquardt's bistable actuator approach and Parker/Beckman's magnetic latching actuator approach is that in the case of the bistable actuator only the opening coil is energized momentarily to cause the armature to shuttle to the open position. To close the valve, only the closing coil is energized momentarily to shuttle the armature to the closed position. Thus the reversing of polarity which is required for the Parker/Beckman valve concept is not required for the Marquardt concept. This aspect simplifies the driving circuitry for the bistable actuator somewhat.

4.3.2 Solenoid Concepts

Solenoid actuator concepts are generally simpler than latching type concepts because they utilize only a single working gap, a single coil, and require no permanent magnets. Typical configurations are shown in Figures 4-3 and 4-4. The disadvantage of the solenoid concept is that it requires power continuously as long as the valve is held in the open position. This feature means that the amount of electrical power that can be put into the solenoid is somewhat more limited to assure that the solenoid will not overheat while it is in the open position. Thus for the relatively small valves under consideration for the Pioneer Venus application solenoid valve power must be limited to values of approximately 10-15 watts. This would mean maximum available pull in current is approximately 1/2 amp. On the other hand since the magnetic type latching actuators require only momentary power, their pull in current may be raised to typical values of the order of several amperes. To return the armature in a solenoid actuator to the closed position the electrical power is simply terminated, thereby, removing the magnetic force and permitting the coil spring to return the armature.

4.3.3 Actuator Materials

Soft magnetic materials typically utilized in electromagnetic actuators are core iron which is then plated to prevent it from rusting, magnetic stainless steel such as type 430F or 446, and vanadium permendur (49% cobalt, 2% vanadium, 49% iron). This latter material again needs to be protectively plated to prevent it from oxidizing. A review of the Curie temperature of these materials was made and it was determined that the Curie temperatures are all in excess of 914^{o}F. Consequently all of these materials appear suitable for use in the actuator for this application. The coil windings are generally made of copper or aluminum and a typical high quality aerospace wire insulation is pyre-ML which features a temperature capability up to approximately 450^{o}F. For higher temperatures, a polyimide insulation available under the tradename Capton is occasionally used. Capton insulation extends the temperature capability to approximately 600^{o}F but results in a larger coil configuration because of the manner in which the Capton is applied and the resultant larger insulated wire diameters. To extend the temperature capability of the coil windings beyond 600^{o}F requires the use of oxides as insulations and the most applicable material combinations appear to be aluminum wire with aluminum oxide and silver wire with nickel oxide. Berylium wire with berylium oxide has also been pursued but the winding technology with the berylium wire is not nearly as far along as that with the aluminum and silver wires. Winding of coils utilizing these oxide insulations is considered to be vastly more difficult than the winding of the more conventional copper or aluminum wires with Pyre-ML or Capton insulation.

The joining of the coil wiring to connector pins is accomplished by means of conventional soldering for temperatures up to approximately 500^{o}F. Beyond that silver soldering, brazing, and eventually welding are employed. A wide range of potting compounds is available for temperatures as high as 914^{o}F and beyond. No particular developmental problems with the potting compounds are expected. The principal developmental problem in achieving 914^{o}F actuator capability appears to be in the winding of the oxide coated coil wiring to assure that the insulation does not crack, chip, or otherwise degrade. It is Marquardt's conclusion that solenoid or magnetic latching actuators with temperature capabilities up to 600°F are essentially state-of-the-art and require no significant development. However, to achieve the 914°F temperature capability, a considerable development effort will have to be expended.

4.4 TECHNIQUES FOR PRESERVING SAMPLE INTEGRITY

Since the cyclic valves analyzed during the study are intended for use as sampling valves on the inlet system of the Pioneer Venus Probe Mass Spectrometer, it is very important that potential sample contamination be carefully considered. To minimize the possibility of poisioning the atmospheric gas sample to be analyzed two approaches have been demonstrated or suggested. One approach is employed in the Parker/Beckman valve wherein a separate bleed is installed on the actuator cavity such that the gas coming in contact with materials in the actuator cavity is bled overboard and is not routed to the Mass Spectrometer. A more positive approach is that proposed in Figure 4-2 which shows a concept utilizing a diaphragm to completely separate the sealing closure and actuator cavities. In this manner only those materials located in the sealing closure cavity are exposed to the gas sample and the volume of the sealing closure cavity containing the gas sample is kept at a minimum. In place of the diaphragm a miniature bellows could be used equally well. This technique was pursued by the Marquardt Company in the design prepared by it and discussed in Section 5. Another important consideration in maintaining sample integrity is the utilization of relatively inert materials in the cavity to which the gas sample is exposed. In this respect and particularly when operating at 914°F plastic and elastomeric materials must be avoided. Rather 300 series stainless steel, ceramics, and some of the noble metals such as gold should be utilized.

SECTION 5

VALVE DESIGN LAYOUT AND PERFORMANCE CHARACTERISTICS

Based upon various fluid system component technology programs performed by The Marquardt Company in support of such government agencies as The Air Force Rocket Propulsion Laboratory, NASA Manned Spacecraft Center, NASA Lewis Research Center, and NASA Langley an optimum valve concept as conceived by The Marquardt Company for the inlet system of the Pioneer Venus Probe Spectrometer was also prepared. This concept is shown in Figure 5-1. The optimum valve features a solenoid type actuator because it is slightly simpler in configuration than the magnetic latching type actuator. However, a bistable actuator such as described in Section 4.3.1 of this report which was previously developed by The Marquardt Company for NASA during a program described in Reference (3) could easily be substituted for this solenoid actuator. Substitution of the bistable actuator for the solenoid actuator would result in no significant weight or envelope changes and would feature peak operating currents of approximately 1 amp.

The optimum valve concept has been designed to fully withstand the 914°F temperature requirement. Thus, this valve could actually be located outside of the pressure vessel of the space probe. To achieve the high temperature capability aluminum coil wiring with aluminum oxide insulation has been selected. This coil wire is wound on an annnodized aluminum bobbin and incapsulated in castable ceramics such as Aremco Products, Inc., Ceramacast No. 511. The coil wiring is brazed to the electrical connector pins which in turn are cast in ceramic headers to insulate them from the soft magnetic material of the actuator. Since the change in resistance of the aluminum wire over the wide temperature range is very large this actuator will inherently draw a large current at the low temperature extreme of the temperature range. To eliminate this undesirable feature and to prevent overheating of the valve at low temperature it is recommended that the valve driver be equipped with a current limiting circuit such that the nominal five watt rating of the solenoid is never exceeded regardless of the operating temperature.

An alternate approach to the utilization of a current limiting circuit in the valve driver would be the substitution of a nickel/silver alloy wirefor the aluminum wire. The change in resistance of the nickel/silver wire with respect to temperature can be controlled by varying the amount of nickel in the wire. The greater the amount of nickel in the wire is the less the change in resistance becomes; however, more nickel also results in higher coil resistivity and therefore significantly higher actuator weight.

The vanadium permendur is recommended as the soft magnetic material since it is the most efficient magnetic material available. To prevent corrosion of this material it is recommended that it be gold plated. The solenoid actuator, of course, utilizes only a single working gap across which the magnetic opening forces are established when the coil is energized and depends upon spring forces to return the armature and poppet to the closed position when the coil is de-energized. In the valve layout shown in Figure 5-1 these return spring forces are generated by means of two axial guidance flexures and a precompressed bellows. The

OPTIMUM VALVE CONCEPT

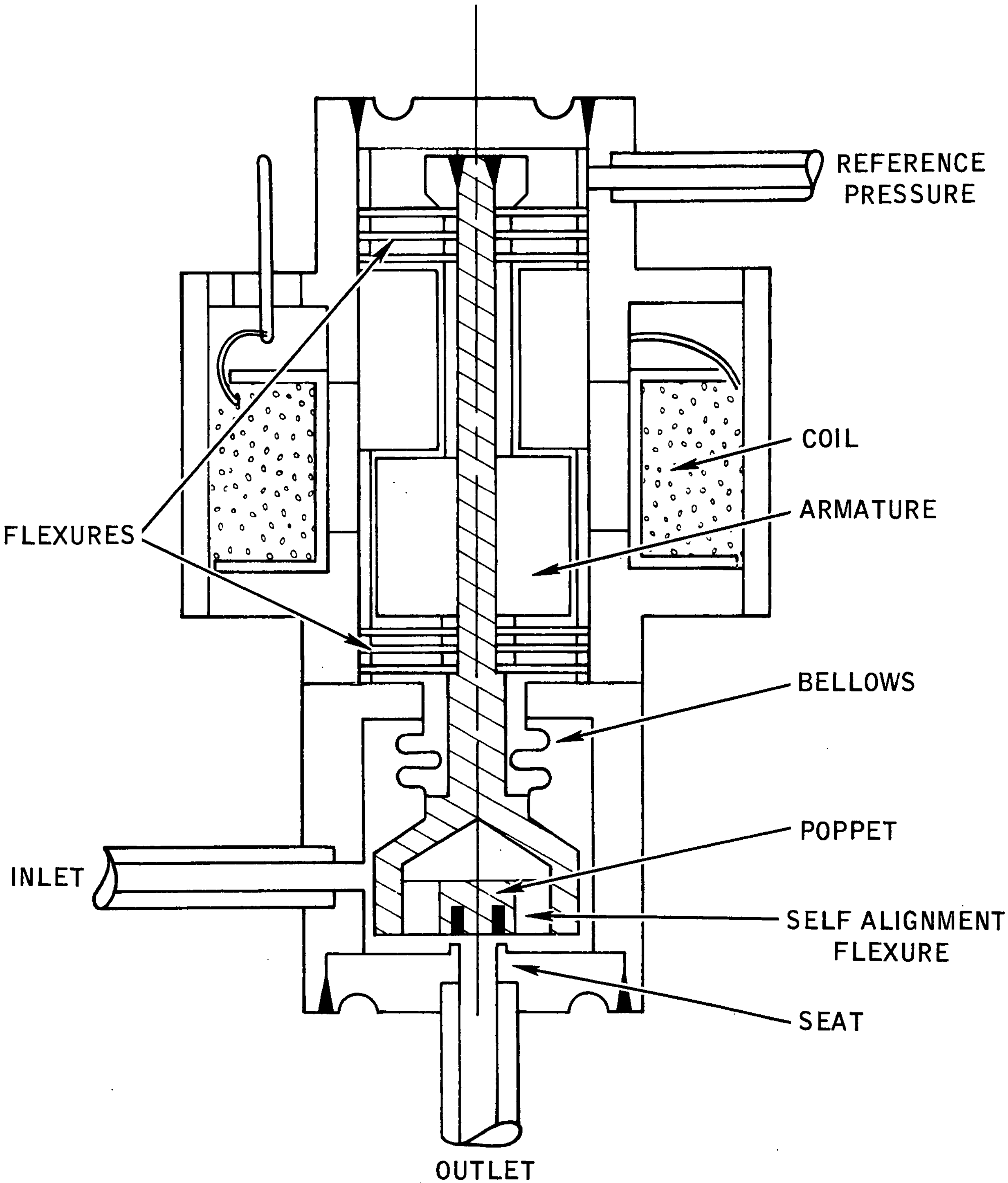


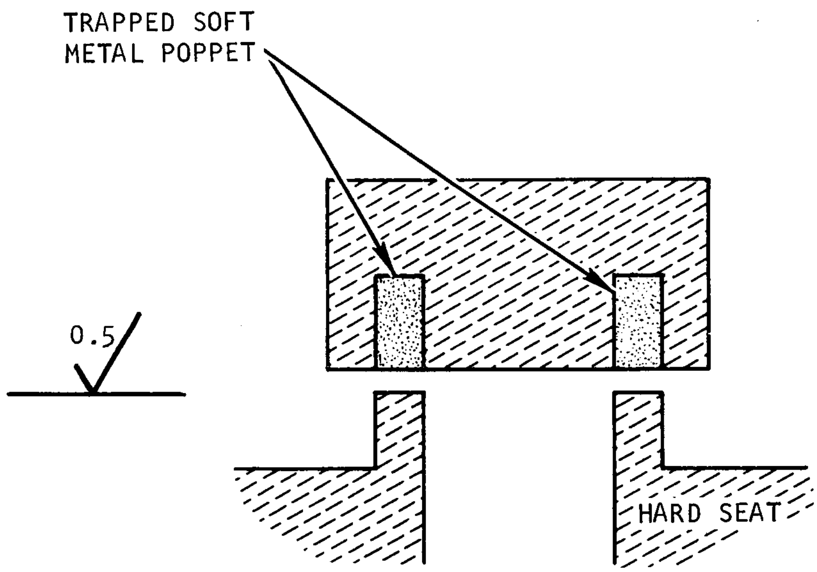
Figure 5-1

axial guidance flexures are located in the actuator cavity and are made of 300 stainless steel. These metallic flexures have been employed by Marquardt in support of several technology programs such as the program described in Reference (4). The principal advantage of axial guidance flexures is their inherent characteristics of featuring very high radial spring rates and relatively soft axial spring rates. Thus, the moving part guided by these flexures is forced to move rigidly along the axis of the guidance flexures and such undesirable features as sliding friction and sloppy clearances are eliminated. Utilization of axial guidance flexures for components required to operate over wide temperature ranges is particularly advantageous since it completely eliminates the potential of jamming of the device due to differences in thermal expansion characteristics of the bore and sliding cylinder utilized in more conventional designs.

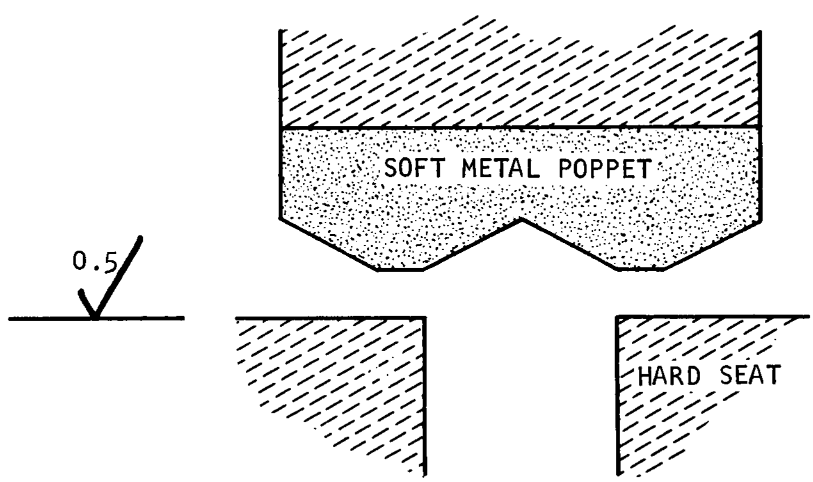
The sealing closure of the optimum valve concept features a flat poppet/seat interface. To assure that the poppet will align with the seat at all times, the poppet has been made an integral part of a self alignment flexure. This type of flexure was developed a number of years ago at the Marquardt Company and is described in Reference (4). The self alignment flexure is simply a flexural U-joint which permits rotation of the poppet out of the plane of sealing surface by as much as $1/2^{o}$. Consequently, any thermal distortion which may occur in the valve parts that assure alignment between the poppet and the seat is compensated for. The self alignment flexure also can be designed to feature a finite axial spring rate such that the impact forces occurring at the poppet/seat interface during closure of the poppet are minimized. For this effect the flexure constitutes a compliant element between the poppet button and the shaft and armature assembly so that only the kinetic energy of the poppet mass rather than that of the total moving assembly must be absorbed at the sealing closure interface. Several material choices are possible for the self alignment flexure and the bellows seal. These include 300 series stainless steel and Inco 718.

Details of the sealing closure interface are shown in Figure 5-2. The sealing principle is based upon coining a soft metal with a very smooth and flat (1/2 AA finish) hard metal. One problem with repeated coining is the flow of the softer material at the edges of the interface. This is avoided by containment of the soft material. By containment of the soft metal plastic strain work hardening and failure due to stress can not occur. Thus, relatively high cycle life can be achieved. The trapped soft metal design of Figure 5-2 shows such a containment approach. This type of sealing closure interface has been successfully demonstrated in support of a Jet Propulsion Laboratory program for approximately 70,000 cycles. Repeatable leakage rates of approximately 1.3×10^{-9} SCC per second of helium at a pressure differential of 50 PSI were demonstrated. The materials of construction used for the JPL program were aluminum 1100 for the soft material and stainless steel for the mating hard seat. The particular sealing closure demonstrated was approximately 1/2 inch in diameter and featured a land width of 0.1 inch. The extrusion gap between the annulus of the seat and the poppet was minimized and was kept below 0.001 inch. Leakage rates beyond the 70,000 cycles did start to increase because of extrusion of the soft aluminum through this extrusion gap. However, it must be recognized that 70,000 cycles life is far in excess of the requirements of the Pioneer Venus Probe Mass Spectrometer Inlet System.

OPTIMUM SEALING CLOSURES



TRAPPED SOFT METAL DESIGN



EXPOSED SOFT METAL SEAL DESIGN

Figure 5-2

The sealing closure of the optimum valve concept is a scaled down version of the sealing closure just described in the preceding paragraph. The effective diameter of the seat will be only 0.030 inch and the land width will be 0.015 inch. To achieve the 914°F temperature capability, gold will be used for the soft material with Inco 718 or 300 series stainless steel for the hard material. The change in material as well as the increased temperature requirement will make a development program necessary. The principal area of concern during this development program will be the adhesion of the metals and the resultant effect on surface finish and leakage. The Marquardt Company has previously developed sealing closure interfaces featuring ceramic on gold for larger valves wherein the adhesion problem did not really become pronounced until after 100,000 cycles.

To effect coining of the soft metal by the hard metal it is necessary to operate at sealing closure interface stresses somewhat above the yield point of the soft material. As an example, the aluminum in the sealing closure discussed in the preceding paragraph was operated at approximately 19,000 PSI and the yield strength of this material in the half hard condition is approximately 17,000 PSI. A somewhat simpler version of the soft metal/hard metal sealing closure is shown in the lower half of Figure 5-2 and is identified as the exposed soft metal seal design. This design eliminates the need for the relatively tight extrusion clearances but since the soft metal is not fully contained features considerably less cycle life. However, since the cycle life requirement of the sampling valves for the Pioneer Venus Mission application is significantly under 1,000 cycles, this sealing closure interface design may very well be sufficient. As conceived here the sealing closure materials, interface stresses, surface finishes, and land width would be the same as that for the trapped soft metal design.

As mentioned previously, the valve features a bellows seal between the sealing closure cavity and the actuator cavity to minimize possible sample contamination. To minimize the actuation forces and, therefore, the size of the solenoid actuator the actuator cavity must however be pressurized to the same pressure as the gas sample. This is accomplished by simply plumbing a reference pressure line to the outside of the space probe. This reference pressure line can be eliminated and the actuator cavity can be operated by simply exposing it to the low pressure of the space probe environment (8 PSIA GN_2); however, in this configuration the size of the solenoid actuator must be increased to overcome the differential pressure forces acting on the bellows effective area and it is estimated that the resultant valve weight would thereby roughly triple.

The performance characteristics of the optimum valve as presented in Figure 5-1 are listed in Table 5-I. As evident from this table the valve is expected to fully meet all of the requirements of the Pioneer Venus Probe Mass Spectrometer Inlet System and could in effect be located outside of the spacecraft pressure vessel. In the event that the valve will be located inside the spacecraft pressure vessel such that the actuator is exposed to the 8 PSIA and 125°F gaseous nitrogen environment the valve actuator could be modified to feature more conventional coil windings utilizing polyimide insulation and polyimide resins for potting and sufficient thermal resistance between the sealing closure cavity and the actuator to limit actuator temperatures to approximately 570°F. This would still permit operation of the sealing closure cavity at 914°F to prevent condensation of any of the constituents of the gas sample.

TABLE 5-I

PREDICTED VALVE CHARACTERISTICS

Maximum Operating Temp. (^{O}F), Actuator	914
Maximum Operating Temp. (^{O}F), Valve	914
Leakage @ 50 PSI He (SCC/SEC) $70^{O}F$	2×10^{-9}
Electrical Power @ 30 VDC & $70^{O}F$ (Watts)	5
Electrical Power @ 30 VDC & $914^{0}F$ (Watts)	5
Weight (Lbs.)	0.15
Envelope Inch Dia. x Inch Long	1.0 x 1.5
Materials In Contact with Sample	Gold Inco 718 304C Cres
Special Requirements	Seperate Tube for Reference Pressure Current Limiting Driver

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The valves survey performed in support of the study of multiple cycle valves for application to the inlet system of the Pioneer Venus Probe Mass Spectrometer concluded that valves are available from Parker/Beckman and Energy Research and Generation, Inc. which approach the requirements as specified for this application. These valves feature a maximum temperature capability of 437°F as compared to a specification requirement of 914°F. There is also a small valve available from Pyronetics which features a temperature capability of 300°F. The temperature limiting materials in the Parker/Beckman and ERG valves are the coil wiring insulation and the potting. By substituting polyimide insulation and polyimide resins the temperature capability of these valves could be upgraded to approximately 570°F. Further increases in temperature capability requires substantial redesign and the performance of an extensive development program.

A valve design was proposed by Energy Research and Generation, Inc. which promises to meet the 914°F temperature requirement. In addition as part of this study, the Marquardt Company prepared a design concept which also fully meets the Pioneer Venus Mission requirements. Both the ERG valve design and the optimum valve design prepared during this study have the capability of being located outside of the Pioneer Venus Probe pressure vessel and being fully exposed to the Venus environment. If a decision is made in the future to locate these sampling valves inside the Venus Probe pressure vessel such that they would be in a gaseous nitrogen environment featuring a minimum of 8 PSIA pressure and a maximum of 125°F temperature the required valve development effort could be reduced by developing the valve actuator for a 570°F temperature capability only (the gas sample cavity will still be rated at 914°F) and thereby eliminating certain actuator development costs. Also if a decision is made that sampling of the Venus atmosphere down to an altitude of approximately 20 miles is sufficient it appears that the Parker/Beckman and ERG valves in their present configuration or possibly as slightly upgraded as far as actuator materials are concerned are sufficient.

To substantiate the 437°F temperature capability as well as other valve performance characteristics such as leakage, operating pressure, cycle life, acceleration capability, low temperature capability (-75°F), and power requirements over the temperature range it is recommended that two or three sampling valves be procured from both ERG and Parker/Beckman and that a performance evaluation program be conducted with these valves. This test program should be patterned along the lines of the qualification program detailed in Appendix A. It is estimated that this evaluation program, including the procurement of valves from the two vendors, could be accomplished in a period of 4-6 months.

To achieve the total temperature capability of 914^{o}F it is recommended that a complete valve development program be initiated which will take a valve concept including alternate valve component configurations from a breadboard through a brassboard to a prototype and ultimately to a flighttype valve configuration to assure that a highly reliable multiple use product is developed. It is estimated that a development program of this magnitude will require approximately 2 years.

SECTION 7

REFERENCES

(1) Pioneer Venus, Report of a Study by the Science Steering Group, NASA-Ames Research Center, June 1972.

(2) Pioneer Venus, "Atmospheric Inlet System for the Pioneer Venus Probe Mission Mass Spectrometer", Document No. PV-1003.00, NASA-Ames Research Center, August 1972.

(3) Bistable Actuator, by H. Wichmann, Marquardt Report No. MP-1224, NASA Contract NAS 9-1677, January 1964.

(4) Advanced ACS Valve Development Program, by G. T. Pond and H. Wichmann, The Marquardt Company Report No. AFRPL-TR-69-250, December 1969.

(5) Models of the Venus Atmosphere (1972), NASA SP 8011, Revised September 1972.

APPENDIX A

EPS 402, "SAMPLING VALVE FOR THE VENUS PROBE MASS SPECTROMETER"

THE Marquardt COMPANY
CCI Corporation

ENGINEERING PROCUREMENT SPECIFICATION

ISSUED: 3/27/73

TITLE: SAMPLING VALVE FOR THE VENUS PROBE MASS SPECTROMETER

PROJECT ENGINEER:
H. Wichmann

CODE IDENT. 86845

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1. SCOPE

This specification establishes the requirements for a high temperature, high pressure, normally closed or latching type solenoid actuated cyclic valve. This valve is a component in one of several inlet systems under consideration for a mass spectrometer to be carried on an unmanned spacecraft to Venus.

2. BACKGROUND

Present plans are to launch a spacecraft to Venus in 1978. Following a cruise period of approximately 125 days one of the sections of the spacecraft referred to as the large probe and carrying a mass spectrometer will separate from the spacecraft. Approximately 15 days later this probe will enter the atmosphere of Venus and at an altitude of 43.5 miles above the surface of Venus, deploy a braking parachute. At this time the first sample of the Venus atmosphere will be admitted to the mass spectrometer inlet system for analysis. This sampling procedure will repeat in 3 minute intervals and, just prior to impact, in 6 minute intervals over a total descent period of 72 minutes.

3. APPLICABLE DOCUMENTS

The following documents of latest issue effective form a part of this specification as indicated herein. In the event of conflict between the documents listed below, and this specification, the latter shall govern.

3.1 Specifications

Federal

PPP-T-60B Tape, Pressure Sensitive, Adhesive, Waterproof for Packaging
PPP-B-566C Boxes, Folding, Paperboard
PPP-B-676C Boxes, Setup, Paperboard
TT-I-737A Isopropyl Alcohol

Military

MIL-P-26514 Polyurethane Foam, Rigid or Elastic for Packaging
MIL-C-26861 Cushioning Material, Resilient Type, General

NASA

MSFC-237 Solvent, Precision Cleaning Agent
NHB-5300.4(3A) and ARC Supplement No. 1 Requirements for Soldering Electrical Connections
MIL-P-27401 Propellant, Pressurizing Agent, Nitrogen
MIL-P-27407 Propellant, Pressurizing Agent, Helium

The Marquardt Company

MPS 210 Cleanliness Requirements for Reaction Control System Engines

3.2 Standards

Military

MIL-STD-810 Environmental Test Methods
MIL-STD-143 Specifications and Standards, Order of Precedence for the Selection of
MS 33586 Metals, Definition of Dissimilar
MIL-I-8500 Interchangeability
MIL-STD-130 Identification Marking of United States Military Property
MIL-Q-9858 Quality Program Requirements

3.3 Other Documents

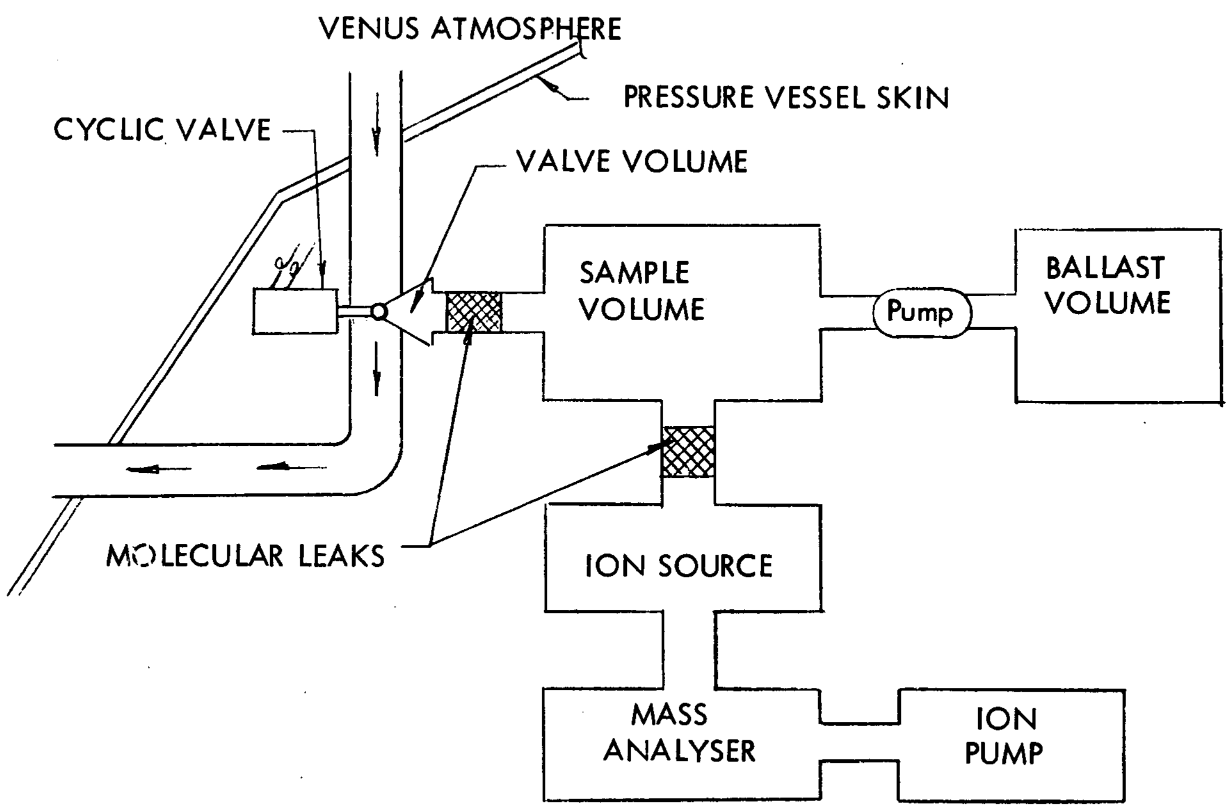
Military

MIL-HDBK-5A Metallic Materials and Elements for Flight Vehicle Structures

4. REQUIREMENTS

4.1 Performance

The valve shall provide positive on-off control of atmospheric gas from the probe inlet duct to the valve volume. A typical schematic representation of the valve relative to the spectrometer and other system components is shown below.



In this system the ambient atmospheric gas is bled past the valve poppet. When activated by a command pulse, the valve will allow the gas to fill the valve volume. A molecular leak between the valve volume and the sample volume will prevent "flooding" of the system while the valve is open. After the valve closes, its low leak rate will limit dilution of the gas sample as it "leaks" into the sample volume. The sample volume is maintained at a constant pressure by a pumping system. This constant pressure and a second molecular leak between the sample volume and the ion source provides a constant mass flow through the ion source during the analysis period.

4.1.1 Functional Characteristics

4.1.1.1 Flow Parameter

The valve flow parameter, C_dA, shall be approximately 8.63×10^{-5} in^2.

4.1.1.2 Fully Open Times

The fully open time shall not exceed those specified for the operating parameter limits indicated below.

Fully Open Time (secs)	Operating Voltage (Vdc)	Inlet Pressure (Psia)	Inlet Gas Temperature (°F)
1.0	22 - 30	1400	914
2.0	22 - 30	0.81	-75

If thermal isolation of the valve coil is required, the vendor shall specify the maximum ambient temperature to which the coil for his valve may be exposed and the approximate heat rate which has to be removed from the coil based on maximum coil and inlet gas temperatures.

4.1.1.3 Opening Time

The interval from receipt of the electrical signal at the valve solenoid to the time the valve is fully opened shall be less than 500 milliseconds, under the operating conditions of 4.1.1.2.

4.1.1.4 Closing Time

The interval from termination of electrical signal at the valve solenoid to the time the valve is fully closed shall be less than 500 milliseconds under the operating conditions of 4.1.1.2.

4.1.1.5 Internal Leakage

Leakage through the closed poppet/seat interface shall not exceed .002 atmospheric cc/hr. over the pressure and temperature range specified in 4.2.2.

4.1.1.6 Reverse Leakage

Leakage through the seated poppet of the valve shall not exceed 0.5 atmos cc/hr of nitrogen gas at room ambient conditions, when the valve outlet port is pressurized to 20 psig.

4.1.1.7 External Leakage

Leakage from the valve shall not exceed .001 atmos cc/hr of helium gas over the pressure and temperature range specified in Section 4.2.2 with valve open and the outlet plugged.

4.1.1.8 Operating Cycles

The valve shall meet the requirements of this specification after 500 actuations at an operating voltage of 28 Vdc, and at a non-flowing GN_2 inlet pressure of 20 psig.

4.1.1.9 Continuous Operation

The valve shall suffer no performance degradation after a voltage of 30 Vdc is applied continuously for a period of 1.0 hour under conditions of zero flow.

4.2 Operating Environment and Conditions

4.2.1 Fluid Media

The valve will flow gas consisting primarily of CO_2 and H_2O, with other constituents in approximately the following ranges:

HBr, HI	$<$	1000 ppm
Hg		10 - 1000 ppm
CO		50 ppm

Other gases in the range below 10 ppm include H cl, HF, HgI_2, H_gBr and COS.

4.2.2 Environmental Pressure and Temperature

Figure I shows the pressure and temperature conditions for the altitude between 43.5 miles to ground level on Venus. Atmospheric sampling for the mass spectrometer will take place throughout this range.

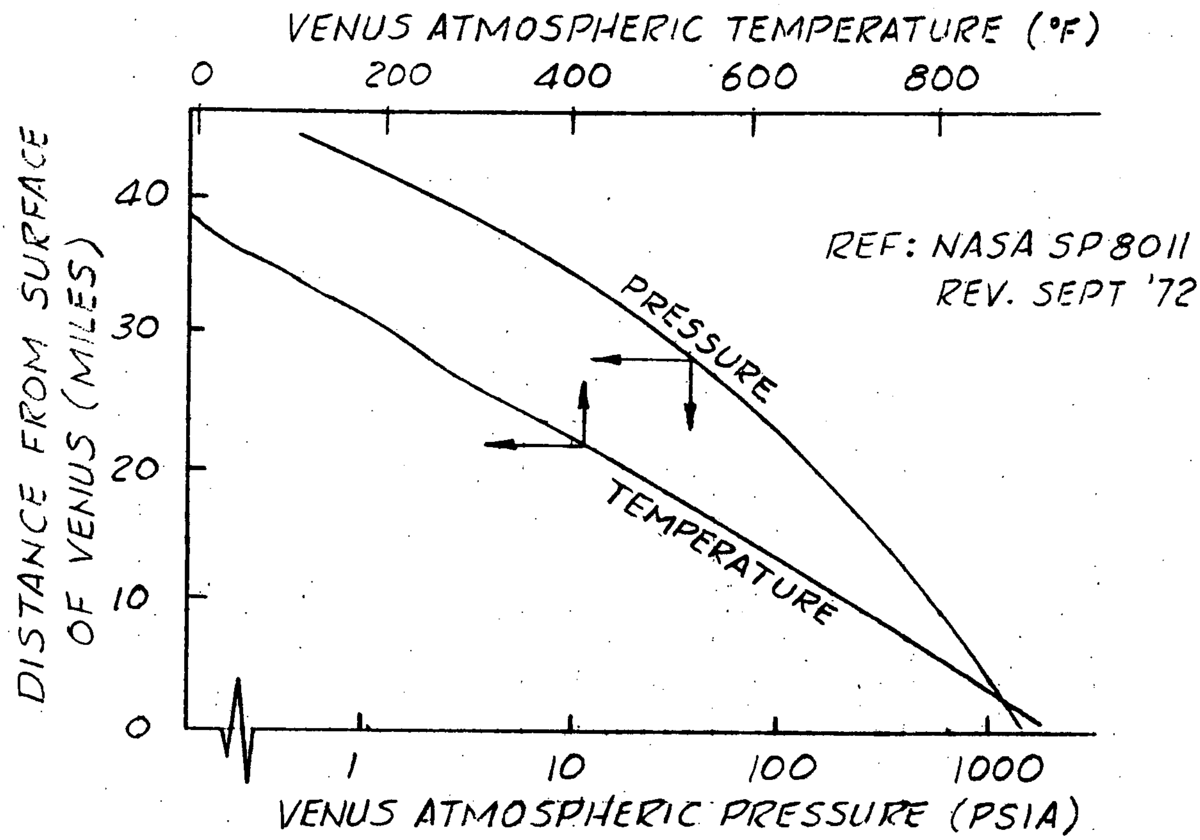


FIGURE 1: VENUS TEMPERATURE & PRESSURE vs ALTITUDE

4.2.2.1 Operating Temperature

Ideally the valve fluid flow cavity should be capable of operating up to the maximum inlet gas temperature of 914°F to prevent the condensation of the inlet gases. (The ideal temperature applies to the valve actuator although it could more readily be thermally isolated from the valve fluid flow cavity.) However, since this temperature may be difficult to meet, lower operating temperatures are also of interest. These lower temperatures would apply if the inlet plumbing to the valve were allowed to remove a certain amount of heat from the gas sample or if the sampling mission were terminated prior to reaching the Venue surface. Consequently, valve suppliers are encouraged to propose valves having lower temperature capability to state what the maximum operating temperature is and what redesign, if any, would increase this temperature.

4.2.3 Shock, Acceleration and Vibration

The valve shall meet the functional requirements of this specification after exposure to the following shock, acceleration and vibration conditions.

4.2.3.1 Shock

Plus and minus 15g peak, terminal peak sawtooth of 8 millisecond duration along any axis.

4.2.3.2 Acceleration

The valve while closed shall be capable of withstanding a deceleration load of 300g's for 10 seconds. Preferred axis or axes along which the load will be applied may be specified by the vendor.

4.2.3.3 Vibration

The random vibration levels for the Venus spacecraft are not known at this time. However, since the valve does not operate during vibration, the only requirement is that no damage is incurred which will in some way affect later performance. The contractor will specify the maximum vibration levels which he would expect his design to be capable of withstanding.

4.3 Design and Construction

4.3.1 Configuration

The valve shall be a normally closed or a latching type two-way configuration operating over the voltage, temperature, pressure ranges of 4.1.1.2

4.3.1.1 Internal Passage Volume

To minimize the effect of the valve internal surfaces on the gas sample, through absorption and chemisorption, the internal surface area of the valve should be held to a minimum.

4.3.1.2 Contamination Sensitivity

Greatest possible contamination tolerance of the valve sealing closure is desirable. The valve supplier shall state the particle sizes and quantities which can be tolerated by the valve per unit gas volume.

4.3.2 Material Selection

MIL-HDBK-5 or similar documents shall be used for the material structural properties for the valve. All material selected for the external and internal surfaces of the valve shall be compatible with the fluids listed in 4.2.1 and with such fluids as are normally used during fabrication and testing of valves for aerospace application; water, MEK, Freon and Hydrocarbon solvents.

4.3.2.1 Selection of Specifications and Standards

All materials, standard parts, and processes shall be controlled by specification, which shall be selected in accordance with MIL-STD-143.

4.3.2.2 Parts, Materials, and Processes

Materials, processes, and electrical/electronic parts used in the construction of the unit shall be subject to TMC approval prior to their use.

4.3.2.3 Fungus Resistance

Materials that are nutrients for fungi shall not be used when their use can be avoided. Where used and not hermetically sealed, they shall be treated with a suitable fungicidal agent. If they are used in a hermetically sealed enclosure or if they are used and stored in a continuously controlled environment, fungicidal treatment will not be necessary.

4.3.2.4 Corrosion Resistance

All parts shall be made of materials (or coated with materials) which are corrosion resistant or compatible with any environments likely to be met in testing, cleaning, storage or service. Particular attention shall be paid to the prevention of galvanic, intergranular or concentration cell corrosion, and to stress-corrosion or hydrogen-stress cracking.

4.3.2.5 Dissimilar Metals

The vendor shall avoid use of dissimilar metals as defined in MS33586, or shall provide suitable protection in cases where such contact is unavoidable.

4.3.2.6 Lubricant

It is desirable that the valve require no lubrication. If lubrication is essential for unit assembly, the lubricant and lubricant application points shall be restricted to those approved by TMC.

4.3.2.7 Soldering

Soldering of electrical connections shall be performed in accordance with provisions of NHB 5300.4 (3A) and ARC Supplement No. 1.

4.3.2.8 Potting

The solenoid coil cavity shall be potted, in accordance with supplier procedures approved by TMC, to prevent the coils from shorting to the case chafing of the coil leads and entrance of dirt or moisture.

4.3.2.9 Cleanness

The unit shall be cleaned, in accordance with supplier procedures approved by TMC, to meet the requirements of MTS 210.

4.3.3 Proof Pressure

The valve shall withstand a pressure of 2100 psig for a period of 1.0 minute without incurring external leakage or experiencing degradation of performance.

4.3.4 Burst Pressure

The valve shall withstand a pressure of 3150 psig for a period of 1.0 minute without rupturing.

4.3.5 Weight

Primary emphasis is to achieve the low leakage requirement and the high pressure and temperature capability of this specification. To this end, the weight constraint is secondary.

4.3.6 Power Limitation

The total power required by the valve should be minimized and should not exceed 5 watts over the voltage and temperature range specified in Section 4.1.1.2.

4.3.7 Corona Discharge

The valve shall not exhibit corona discharge while operating in an environmental pressure of 1×10^{-5} torr or greater.

4.3.8 Dielectric Strength

The valve shall withstand a potential of 1000 V rms at 60 HZ applied for 1.0 minute at room temperature between the coil and case without evidence of failure or current leakage greater than 0.5 milliampere.

4.3.9 Insulation Resistance

A resistance of 500 megohms or greater shall be measured between coil and case at a voltage of 500 Vdc applied at room temperature.

4.3.10 Grounding

Solenoid coils shall employ current return wires and shall be electrically isolated from the case and each other.

4.3.11 Electrical Bonding to Ground

The unit will be electrically bonded to ground by direct metal-to-metal contact over the entire mounting surface of the valve. The valve mounting surface shall be free of any electrically non-conductive finishes.

4.3.12 Bond Resistance

The d-c resistance measured across any bond shall be less than 10 milliohms.

4.3.13 Assembly Bonding

All metallic inner and outer cases of the assembly, including end fittings, shall be considered electrically as extensions of the ground reference plane (spacecraft structure and equipment platform).

4.3.14 Explosion Proofing

All details of design shall minimize the possibility of explosion. Electrical components, energized or de-energized, shall not provide an ignition source for any explosive mixture surrounding the unit.

4.3.15 Interchangeability

Each valve shall be directly interchangeable in form, fit, and function with other valve of the same part number.

4.4 Workmanship

Workmanship shall be of high quality with particular attention paid to neatness and thoroughness of soldering, wiring, marking of parts and assemblies, and freedom from burrs and sharp edges.

4.5 Identification and Marking

The unit shall be identified and marked in accordance with provisions of MIL-STD-130. Identification data shall include, but not be limited to, the parts and serial numbers.

4.6 Storage

The valve shall be capable of being stored at a temperature of 70 $\pm$ 20°F and a maximum relative humidity of 60 percent for a minimum of three years without requiring any repair, maintenance, or retesting. The unit shall be capable of being stored for a minimum of one year at a temperature of 70 $\pm$50°F and a maximum relative humidity of 90 percent without requiring any repair, maintenance, or retesting.

5. QUALITY ASSURANCE PROVISIONS

5.1 General Requirements

Unless otherwise specified in the Purchase Order or Statement of Work, the supplier shall be responsible for the performance of all test requirements specified herein. The supplier may utilize his own facilities or any commercial facilities acceptable to TMC. Copies of all documents which control the materials, processes, manufacturing and acceptance and qualification testing of the valve shall be made available to TMC for review. TMC shall have the right to witness acceptance and qualification tests if they so desire. The supplier shall provide 2 working days advance notice of all acceptance tests.

5.2 Quality Program

The quality program shall be in accordance with MIL-Q-9858A.

5.3 Acceptance Tests

Acceptance tests are tests performed on valves to show that they are representative of and the performance is equivalent to, the requirements specified in this document. All valves delivered shall have successfully met the requirements of a visual inspection and acceptance tests. Compliance shall be certified on the acceptance test data sheets, a reproducible copy of which shall accompany each unit delivered to TMC.

5.3.1 Acceptance Test Sequence

The acceptance tests shall be performed in sequence shown below and as described in Test Methods. Any alternate test sequence shall be subject to TMC approval prior to performing tests.

a.	Examination of Product	5.3.2.1
b.	Coil Resistance	5.3.2.2
c.	Dielectric Strength Test	5.3.2.3
d.	Insulation Resistance Test	5.3.2.4
e.	Proof Pressure Test	5.3.2.5
f.	External Leakage Test	5.3.2.6
g.	Operational Cycling Test	5.3.2.7
h.	Pressure Drop Test	5.3.2.8
i.	Internal Leakage Test	5.3.2.9
j.	Reverse Pressure Test	5.3.2.10
k.	Thermal Test	5.3.2.11
l.	Response Test	5.3.2.12
m.	Pull-In and Drop-Out Current Test	5.3.2.13
n.	Cleanness Test	5.3.2.14

5.3.2 Test Methods

5.3.2.1 Examination of Product

Each valve shall be examined for conformance with

4.4, Workmanship, and
4.5, Identification and Marking

5.3.2.2 Coil Resistance (s)

The coil resistance(s) shall be measured at room ambient temperature and then corrected to the equivalent -75°F resistance value. The equivalent -75°F resistance shall not be less than TBD.

5.3.2.3 Dielectric Strength Test

The valve shall be tested to, and shall comply with, the dielectric strength requirements of 4.3.8.

5.3.2.4 Insulation Resistance Test

The valve shall be tested to, and shall comply with, the insulation resistance requirements of 4.3.9.

5.3.2.5 Proof Pressure Test

The valve shall be subjected to a proof pressure test to verify that the requirements of 4.3.3 have been met. The test shall be conducted with a nitrogen gas inlet pressure per 4.3.3 and the unit immersed in liquid. There shall be no external leakage, in the form of gas bubbles, after 0.5 minute with the valve closed and after 0.5 minute with the valve open and outlet port blocked.

5.3.2.6 External Leakage Test

The valve shall be subjected to an external leakage test to verify that the requirements of 4.1.1.7 have been met. The test shall be performed while the valve is held in the open position. During the test, the outlet port shall be blocked and a pressure of 1400 ± 50 psig applied to the inlet port.

5.3.2.7 Operational Cycling Test

The valve shall be subjected to 5 cycles of on-off operation. The test shall be conducted with a no flow inlet pressure at 500 psig, using GN_2 as the test fluid. The test shall be performed at a maximum cycling rate of one cycle per 30 seconds, with 28 ± 1 vdc being applied for a minimum of 1 second during each cycle.

5.3.2.8 Pressure Drop Test

The valve shall be installed in a suitable pressure drop setup. While the valve is Open and and at an inlet pressure of 500 psig GN_2 appropriate measurements for the calculation of C_dA shall be made. The measured valve C_dA shall meet the requirements of 4.1.1.1.

5.3.2.9 Internal Leakage Test

The valve shall be subjected to an internal leakage test to verify that the requirements of 4.1.1.5 have been met. Ambient leakage shall be measured at 100 ± 5 psig GN_2. When determining the valve internal leakage rate, the inlet port shall be pressurized and leakage shall be measured at the valve outlet port.

5.3.2.10 Reverse Pressure Test

The valve shall be subjected to a reverse pressure test to verify that the requirements of 4.1.1.6 have been met. During the test, a pressure of 20 ± 1 psig shall be applied at the valve outlet port and the leakage rate shall be measured at the valve inlet port.

5.3.2.11 Thermal Test

The valve temperature shall be raised to the maximum operating temperature per 4.2.2.1 and 1400 ± 50 psig and leakage per paragraph 5.3.2.9 shall be measured. The valve shall be cycled once and the leakage measurement repeated.

5.3.2.12 Response Test

The valve shall be subjected to a response test to verify that the requirements of 4.1.1.3 and 4.1.1.4 have been met. The test may be conducted at room ambient temperature provided the specified input voltage is corrected for the corresponding extreme ambient temperature. During the test, the valve inlet port shall be pressurized with nitrogen gas first at 1400 ± 50 psi and again at 0.80 ± 0.1 psi. The method of correcting for extreme temperatures and measuring valve opening and closing times shall be subject to TMC approval.

5.3.2.13 Pull-In and Drop-Out Current Test

The valve inlet port shall be pressurized with nitrogen gas to 1400 ± 50 psig. The input voltage shall be increased from 0 to 20 vdc at a rate of 20 ± 10 vdc per minute. The voltage and current at which the valve opens to maximum flow (pull-in current) shall be recorded. The inlet pressure then shall be established at 1200 ± 45 psig with gas flowing through the valve. After applying 20 vdc, the input voltage shall be decreased to zero at a rate of 20 ± 10 vdc per minute. The voltage and current at which the valve closes (drop-out current) shall be recorded.

5.3.2.14 Cleanness Test

The valve shall be subjected to a cleanness test in accordance with MPS210. Prior and subsequent to the test, the valve shall be thoroughly dried in a vacuum oven. Internal cleanness shall be verified by performing a rinse test using isopropyl alcohol conforming to TT-I-735. The particulate count of the first 100 milliliters of effluent shall meet the requirements of MPS 210. The valve shall be protected against recontamination prior to removal from the contamination-controlled area.

5.4 Qualification Tests

Three valves shall be subjected to qualification tests. Each valve shall have first been tested per the acceptance test section of this specification. Tests shall be performed in the sequence indicated in the matrix below. A report summarizing the results of these tests shall be submitted to TMC within 30 days of the completion of the final test and will include three copies plus one reproducible.

QUAL. TEST MATRIX

Test	Para.	Valve Number 1	Valve Number 2	Valve Number 3
		Test Sequence		
Shock	5.4.1	3	2	2
Acceleration	5.4.2	2	1	1
Vibration	5.4.3	1		
High and Low Temperature Gas	5.4.4		3	
Life Cycle	5.4.5			3
Mission Duty Cycle	5.4.6		4	
Proof Pressure	5.4.7	7		5
Burst Pressure	5.4.8	9		
Operational Cycling	5.3.2.7	5	5	6
Internal Leakage	5.3.2.9	4,8	6	7
Visual Insp.	5.4.10	6,10	7	4,8

5.4.1 Shock Test

The valve shall be subjected to a total of six tests, one forward and one reverse along each of three mutually perpendicular axes. The supplier is free to specify the orientation of the axes for these tests. The shock shall be of 15g magnitude, terminal peak sawtooth of 8 milliseconds duration. The balance of the shock test procedure shall be per Procedure I, method 516.1, paragraph 3.3, basic design test, of MIL-STD-810B.

5.4.2 Acceleration

The procedures of MIL-STD-810B method 513.1 shall apply for the setup and performance of this test except that the acceleration level shall be 300g, and the duration, 10 seconds. The axis along which the acceleration shall be applied may be determined by the supplier.

5.4.3 Vibration

As specified in paragraph 4.2.3.3 the vibration levels for the valve are not known at this time. Therefore, those levels which the supplier feels his valve to be capable of will provide the random levels for this test. The valve will first undergo a 2g sinusoidal resonant sweep along each of the three axes selected by the supplier for the random tests. The complete sinwave displacement frequency curve shall be per figure 514.1-1 of method 514.1 of MIL STD-810B. Duration of the sweep may be limited to a total of approximately 10 minutes with a logarithmic sweep rate. The resonance search will be followed by a random vibration as specified above. Duration of the random vibration will be 10 minutes from 5 to 2000 cps and 10 minutes from 2000 to 5 cps, along each of the 3 axes.

5.4.4 High and Low Temperature Gas Exposure

The valve shall flow for a period of 2 minutes, a mixture of 95% CO_2 and 5% H_2O at an inlet pressure of 1400 psig and a temperature of 914°F or as indicated in paragraph 4.2.2.1. The high temperature test will be repeated 5 times, once each at 22, 24, 26, 28 and 30 vdc. Off times between the flow tests shall be 20 minutes.

5.4.5 Life Cycle

The valve will be cycled 100 times, 1.0 second open followed by 10.0 seconds closed, at inlet pressures of 16, 400, 800, 1100 and 1400 psig for a total of 500 actuations. Operating voltage will be 28 vdc. The order of tests shall be from low to high pressure and at ambient pressure. The tests will be continuous for each pressure. Valve internal leakage shall be measured per 5.3.2.9 at the end of each 100 cycles.

5.4.6 Mission Duty Cycle

The valve will be operated 2 seconds on, and 2 minutes off a total of 3 times at 28 vdc with the following GN_2 pressure/temperature inlet conditions:

Test	1	2	3	4	5	6	7	8
Cycles	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
Pressure (psia)	1	203	405	610	810	1010	1200	1415
Temperature (°F)	-75	+65	210	355	500	650	790	914

5.4.7 Proof Pressure Test

The valve, closed, shall be subjected to an inlet pressure of 2100 psig GN_2 for a period of 1.0 minute. The gas temperature will be 60 to 90°F.

5.4.8 Burst Pressure Test

The valve, closed, shall be subjected to a hydrostatic inlet pressure of 3150 psig for a period of 1.0 minute.

5.4.9 Response

5.4.10 Visual Inspection

As required in the qualification test matrix table in paragraph 5.4, the valve will be disassembled and a visual inspection performed to assess the effects of tests to that point. Critical dimensions such as housing diameter, poppet and valve seat surfaces and similar parts of the valve subject to wear and dimensional change will be measured and compared with pre-qual test dimensions. Photographs will be used to record changes occurring on wear surfaces.

6 PREPARATION FOR DELIVERY

6.1 General

Unless otherwise specified in the contract or purchase order, valves procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

6.1.1 Retention of Cleanness

Following the acceptance cleanness test, the unit shall be dried in a vacuum oven. Prior to packaging and packing for shipment, the unit shall be sealed in a contamination barrier bag. A pre-cleaned nylon bag shall be used for port closure. The bag shall be retained by pressure sensitive tape, conforming to PPP-T-60 or equivalent, applied over the bag without contacting any part of the unit.

6.1.2 Special Labeling

The contamination barrier bag shall have a label to caution against opening the bag except in a contamination-controlled area.

6.2 Unit Packaging

Each bagged unit shall be inserted into a unit container. Additional cushioning material shall be used to fill all voids and prevent movement of the unit during handling and shipping. The container shall be sealed using tape conforming to PPP-T-60 or equivalent.

6.3 Unit Container Design

The unit container shall be a fiber box conforming to PPP-B-566 or PPP-B-676. The unit container shall be prelined (top, bottom, sides) with foam cushioning material conforming to MIL-P-26514 or MIL-C-26861. The cushioning material shall be a minimum of one inch thick.

6.4 Packing

Any number of unit containers shall be uniformly loaded into a shipping container. Gross packed weight of the shipping container shall not exceed 40 pounds. The shipping container shall provide protection for each unit and unit container during domestic shipment and handling and shall meet the minimum packaging requirements of the common carrier (if so shipped) for safe transportation at the lowest rate to the point of delivery.

6.5 Marking

Each unit container and shipping container shall be labeled, tagged, or marked to show at least the following, unless otherwise noted:

(a) Item name
(b) Part number and revision letter
(c) Contract or purchase order number
(d) Supplier's name or code number
(e) TMC serial number (unit container only)
(f) Quantity
(g) Date of manufacture (unit container only)
(h) Fragile - Handle with Care
(i) Do not open sealed bags in receiving inspection (shipping container only)

6.6 Required Documentation

Shipping invoices, etc. accompanying the end-item package shall be attached to the exterior surface of the shipping container. Attachment shall be in a manner that will preclude loss of these data during handling and shipment by common carrier.

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