Journal of Ocean Engineering and Technology, Vol. 4, No. 1, pp. 25~34, June 1990

⦿Technical Information

Oil Country Tubular Goods (OCTG)－Casing/Tubing Connections

Hong Ou Kim*

(*Received June*, 9, 1990)

OCTG의 케이싱/배관연결

김 홍 우

Key words : Tubular Connection(배관연결), Connection Design(배관설계), Connection Threads(연결나사), Thread Seals(나사밀봉), Connection Requirement(배관요건)

抄 錄

케이싱과 배관 연결(connection)의 구조적이고 기능적인 능력은 가스와 기름을 안전하고 효과적으로 발견하고 개발하는데 매우 중요하다. 이 글에서는 이러한 연결에 관한 일반적이고 기술적인 정보를 소개하였다.

1. Introduction

The drilling, completion and production or injection of oil/gas wells is highly dependent upon the capability of the tubulars used. Since the tubular capabilities are usually governed by the connection capabilities, casing and tubing string designs cannot be completed until connections have been selected. For the past few years the author has been involved with evaluation of tubular connections by means of physical testing and mathematical modeling. During this period of time it came to the author's attention that Korean steel industry and not participated in the competitive business of designing and/or manufacturing tubular connections. The connections are designed and manufactured mostly in Japan, France, Ger-

---

* Member, Senior Facilities Engineer, BP Oil Pipeline Co., Cleveland, Ohio
Currently on loan to Alyeska Pipeline Service Company, 1835 South Bragaw Street, Anchorage, Alaska 99512
U. S. A.

many and U. S. A. With the unprecedented success in the national economy in recent years, Korea is bound to invest in energy resource development in domestic and foreign regions. The objective of this paper is to introduce general informantion on the connections to the technical representatives who will be actively involved in the future development program. The author also wishes to see Korean steel industry soon participate in this potentially lucrative business.

The information introduced consists of a brief discussion of the following topics :

- Connection design and rating
- Connection threads
- Connection seals
- Connection requirements

2. Connection Design and Rating

Tubular connections are like complex pressure vessel closures in that they consist of:

- Threads
- Fluid seals
- Shoulders

Connections utilize high strength pipe body materials because they can be produced more economically in pipe mill processing and because the corrosive limitations of attaching dissimilar materials (galvanic corrosion) are eliminated. Consequently, the material envelope for product development of a connection is limited and the connection strength is dictated by the pipe strength.

The design of a tubular connection is similar to other machine design processes. It is based upon the disciplines of metallurgy, mathematics and strength of materials. It involves the application of machine design, materials properties, failure theory, stress determination and manufacturing methods. Design of tubular connections is based on the following simplifying assumptions:

- The material is ductile
- Service loads are applied statically. In other words, service loads are neither dynamic nor applied by impact
- Service temperature neither exceeds the creep range(about 600°F) nor falls below the nilductility transition temperature (below about 30°F) under load conditions.

The connection design consideration may be, as discussed in connection requirement, broadly separated into three areas:

- Structural integrity
- Fluid sealability
- Field assembly

As will be further discussed subsequently, the typical loading conditions that affect structural integrity of connections are tension or compression, internal or external pressure, both surface and production temperature and corrosion. In high angle directional drilling, bending must also be considered. The same loading conditions also affect sealing integrity of connections, but in different ways. For example, axial tension can break, pull-out or jump-out a connection by exceeding its structural integrity. It can also cause leakage of some connections by plastically deforming threads or reduction the contact bearing pressure of the sealing surfaces. Therefore, tubing designers more often desire tensile strength greater than pipe body in order to not distort seals. Although strength and fluid sealing both involve structural considerations, a separate criteria is required to account for leak resistance considerations.

In order to complete the connection design, it is necessary to build prototypes to empirically evaluate the performance features that were developed in the design concept. Prototypes are also necessary for testing the manufacturing process and for evaluating the design process for size interpolation. The above prototype tests by the connection manufactuers are often called developmental tests. Recently, the finite element method (FEM) has greatly aided the concept evaluation process, and has particularly expedited interpolation of product sizes tested.

When the performance results from the prototype testing have demonstrated the ability of the connections to meet the desired performance characteristics, then the product can be given commercial ratings for marketing. The product manufactures present their ratings in catalogs. Because tubing and casing connections are made of the pipe body material and because of the complexity of the connection geometries, connection's performance ratings are usually expressed in relation to the pipe body (expressed as percent efficiency of pipe body). This also facilitates selection by the user. The connection ratings should be based, as most design engineers agree, upon minimum physical conditions. Some refer to this condition as "Minimum/Minimum". This denotes minimum specified material strength and minimum geometric performance dimensions of the pipe body.

Completion of the connection design further requires:

- Development of production control processes (gauging)
- Quality assurance program

Finally, field trials should be conducted where performance can be scrutinized during the product introduction.

3. Connection Threads

Any thread form has basic features that include height (depth), stab flank angle, load flank angle, root radii, crest radii, and surface finish. All threads follow a helix whether cylindrical or tapered, and so possess pitch and lead. Threads are then matched to opposing threads with either precise interference or clearance or a combination of both. This is controlled by reference to diameters (and tapers for tapered threads). The crests and roots are definitions used for convenient communication purposes. Defining the larger diameters as major diameters and the smaller diameters as minor diameters, the crest diameters of the pin thread is the major diameter, whereas the root diameter is the minor diameter. The box thread is the reverse where the crest diameter is the minor diameter and the root diameter is the major diameter. An ideal diameter fot a basic reference for other dimensions is the pitch diameter, midway between the root and crest diameters and is the same for pin and box. Thread lead is the axial distance that one thread moves onto another for one revolution.

There are many different types of connections and thread variations that have been marketed. However, the basic forms in use today may be classified as (1) round thread form, (2) buttress thread form, (3) shortened (stub) Acme thread form, and (4) reversed flank thread form, which are briefly reviewed in the following.

Tubular connections have traditionally utilized a sharp vee thread, because of the ease of manufacturing 60-degree included angle cutting tools. Line pipe and bolts and nuts still use this thread form (Figure 1). The thread offered adequate performance on non-upset pipe for oil and gas wells ranging in depth of 5000 *ft* or less. This thread was soon replaced with the V-type thread (Figure 2) currently identified as API standard 8-round (with radiused crests and roots) which offered better machining characteristics and improvements in resistance to galling during make-up. As well depths became greater, joint strength requirements increased. Pipe ends were upset in order to improve the tension load resistance of the pin member, In order to avoid adding restriction to inside joint diameter, it was essential to increase the outside diameter of the coupling over that of the non-upset connection.

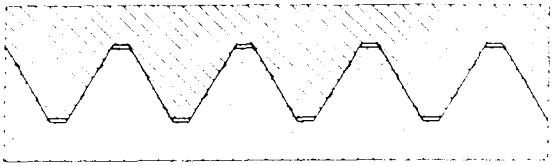

Fig. 1 Line pipe thread form

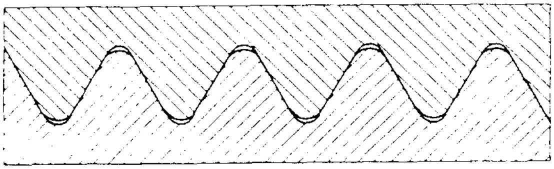

Fig. 2 8-round thread form

If fluid production is principally from one zone, the diameter of the tubing connection is only restricted by the I. D. of the casing. Because deep drilling frequently encounters more than one productive zone, new technology has been introduced in which production can be accomplished from more than one producing formation through a single casing string. These are commonly known as multiple completions. In such cases, more than one string of tubing is run inside of the casing. This has brought about a new concern or "hole clearance". Consequently, joint diameters have become an important factor to consider, and attention has been given to special thread forms which do not require such heavy walls in the critical sections of the joint at the 60 degree V-thread.

One of the earliest changes to a special thread form was found on extreme line casing. This form was obtained from the Acme power thread (Figure 3) by shortening the thread height and altering the flank angles. This modified Acme type of thread offered a load bearing flank that resulted in a stress condition which did not require such heavy wall sections in the box or pin members. This permitted a reduced outside diameter without a corresponding reduction in joint strength. Furthermore, the extreme line joint is one of the earliest joint connections designed with an independent metal-to-metal sealing element. This joint was also incorporated as one of the API standard connections.

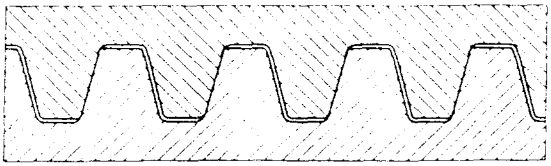

Fig. 3 Acme thread form

With the desire to increase the joint strengths without having to use upset pipe, additional developments were made. Load-bearing thread flank angles were still further changed and the thread root "runouts" were modified so that joint strengths were more nearly equal to the full parting load of the pipe body without using upset pipe. The buttress thread (Figure 4) connection was the result of this continued development. This connection is one of the most widely used oil well casing connections. Like the 8-round and extreme line connection, it is also an API standard connection. The load flank of the buttress connection is almost perpendicular (3 degree angle) to the axis of the joint. The flank angle is less than the friction angle (about 7 degrees) so that the load flank resisted radial separation due to Poisson's effect from axial tension.

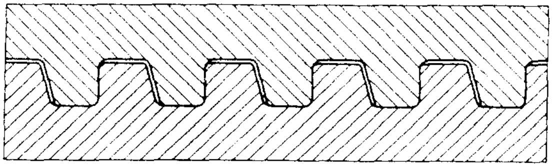

Fig. 4 Buttress thread form

In 1955, Armco Steel Corporation introduced a significantly different thread form on their seal-lock products. The new form comprises a slightly negavtive angle on the load-bearing flank of the thread : i. e., the angle between the face of the load flank and axis of the joint is less than 90 degrees. The merit of reversed angle load flank threads (Figure 5) is that they are believed to draw the pin and box connections radially together when subjected to axial tension. In this manner, they can act to resist pin and box separation under high axial tension. The threads must be sheared or distorted plastically before separation can occur. Therefore, joint strengths equivalent to the full pipe body may be obtainable even without the use of upsets. A similar thread form was also patented by Hydril in 1976 that utilizes dual reversed angle flanks or a helical dove-tail wedge (Figure 6) to resist radial separation due to both axial compression and tension and to act as stop shoulders.

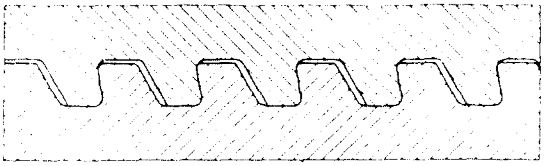

Fig. 5 Reversed angle load load flank thread form

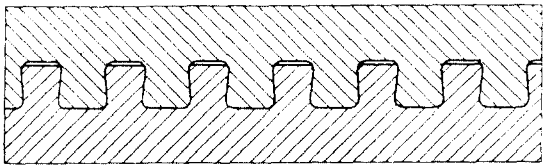

Fig. 6 "Wedge" Thread form

Pressure sealing in tubing and casing connections can be achieved with a number of different mechanisms; thread seals, plastic (elastomeric) seals and metal-to-metal seals. Regardless of the sealing mechanisms, the sealability depends, in general, in (1) component geometry, (2) external forces and reactions, (3) sealing materials, (4) surface topography, and (5) coatings, including lubricants. Thread seals are the most commonly used and are the most economical to manufacture. With the advent of Teflon, plastic seals became extensively used. Metal-to-metal seals have generally been used to seal the more difficult to contain fluids at extreme service conditions.

4. 1 Thread Seals

Thread seals consist of using thread compound within non-mating threads and/or using mating threads. Thread seals are exemplified by API 8-round. This joint is designed in such a manner that when thread are assembled, the annular clearance between mating crest and root is a crescentshaped space having a nominal 0.003-inch height of opening. With proper thread compounds (i. e., Teflon containing) which must plug this annulus, the joint is capable of performing an adequate control for leak resistance provided suitable radial interference is applied to the connection.

Thread compound sealability is a function of application procedure, temperature and time. The grease base of API modified thread compound (75 % content by volume) is the greatest limitation of 8-round threads. It can react with cleaning solvents, condensates, carbonic acid, hydrogen sulphide, and ethane. It dries out with temperature and time, decreasing its resistance to the flow of gases or condensate. A suggested upper limit of temperature is approximately 210°F for long term applications. API modified is 67% metal filler by weight. By volume, they amount to only 25%. It may be possible to increase leak resistance by minimizing clearance between mating thread elements. This may, however, be subjected to detrimental effects from thread wear or galling where service requirements include makeup. If original thread "fit" changes due to wear, it is obvious that leak resistance will be adversely affected.

4. 2 Plastic (Elastomeric) Seals

This concept consists of placing a Teflon seal ring in the groove between mating surfaces. The ring is free to expand or contract with temperature in the direction of fluid flow so that the metal connector walls are not significantly stressed by thermal effects. The seal materials have, in general, thermal coefficients of expansion that are several times that of steel. High flowing temperatures can create enough expansion pressure from the Teflon to separate pin and box threads and extrude the edges of the ring from its groove. Upon cooling, the seal ring contacts, but its shape has changed and it is no longer tight in its groove. A loose seal ring can result in leakage. The plastic seals provide gas tightness to 375°F for thread seals. It also provides redundant sealing capability for metal-to-metal seals.

4. 3 Metal-to-Metal Seals

Metal-to-metal seals first appeared in the oil patch on rotary shouldered connections and on flush type casing to overcome thread sealing limitations. Metal-to-metal seals are of either shouldering type or sliding (flank) type or a combination of the two. The two types of metal-to-metal seals depend on interference that is predetermined by the design concept for the initiation of the sealing interface during assembly. The sliding sealing elements may consist of a curved surface pin seal mating to a conical female seal surface. The purpose of the curved seal is to concentrate the radial interference force to ensure an intimate circumferential contact with the female (box) member of the joint.

Mating of two flat conical surfaces may also be used for sealing purposes. In this case, either short or long conical seals may be used. Long conical seals showed benefits of reduced unit interference force in preventing galling where high radial makeup was incorporated. Shouldering metal seals, on the other hand, utilize mostly compressive axial strain to maintain the sealing interface.

Metal-to-metal seals have proven to be not only reliable, but durable. These independent sealing elements have been used on various products and subjected to practically every conceivable type of service in oil and gas completions. As long as the metal seal coupled casing or tubing is not pulled onto yield, not over-torqued and handled with care, they offer high temperature, high pressure, gas tight performance. Depending on the joint material used, they may be almost indestructible as far as wear or galling from respeated used is concerned. However, they are least capable of field repair; and also, cost the most to make and gauge.

4. 4 Pressure Energized Metal-to-Metal Seals

Pressure energization refers to an increase of contact pressure at the sealing interface caused by an increase of pressure of the fluid being sealed and occurs at a rate greater than the increase of sealed fluid pressure. A pressure energized seal can utilize relatively low contact stress to initiate the sealing interface because the sealed fluid pressure increases the contact pressure at the sealing interface at a rate greater than the increase in fluid pressure.

4. 5 Surface Topography

Surface finsih topography is an important factor controlling fluid sealability. Test data have shown that when two lubricated plane surfaces (either conical, cylindrical, or flat) are held together with interference fit, a surface finish less than 32-microinch roughness is not as good for containment of gases or fluids as surfaces whose roughness ranges above the 32-microinch finsh (measured by General Electric Surface Roughness Comparison Idicators). A smooth surface finish tends to permit "channeling" through the lubricating film between the surfaces. Surfaces having roughness greater than a 32-microinch finish appear to trap lubricant in the surface discontinuities which act somewhat like a gasket with a multitude of tiny high points breaking up continuity of lubricating film, thus preventing channeling. A good surface roughness range for seal finishes was found to be from 32-to 125-microinches, depending somewhat upon the geometry of the discontinuities.

5. Connection Requirement

There are a number of basic functional criteria that must be met in the design of high performance tubular joint connections to be used for casing/tubing string to meet today's need for the oil and gas industries. Joint tensile strengths must be at least equivalent to the load application that would induce the maximum safe working stress in the pipe body. Frequently, this load limit is equal to the parting load of the full pipe body in tension or burst from internal pressure. Most importantly, the joint must be leaktight under all working conditions. The elements effecting leakage control must remain tight under extreme loads in tension, compression, and bending. Temperature changes, whether they are gradual or sudden shock type, must not affect the tightness of the connection. Joints must be suitable for fast and easy makeup. A made-up connection should be sufficiently rugged, withstand various types of service, such as workover, fracing, squeezing, acidizing, drilling bridge plugs, etc. and still be serviceable for production. With all these required features, the economic atmosphere in the industry requires that they be available at minimum cost.

The perfomance requirement of connections briefly described in the above is discussed in detail in the following :

5. 1 High Joint Strength

Joint strength refers to structural integrity of connections subjected to the previously discussed axial tension or compression, internal or external pressure, and bending. Axial tension can break, pull-out, or jump-out a connection by exceeding its structural integrity. Of course, axial tension can also cause leakage of some connections by plastically deforming threads or reducting the contact pressure of the sealing surfaces.

Connection tensile strength is defined as the lesser value of either(1) the product of the minimum specified ultimate strength and the minimum critical section area of the connector, or (2) the minimum pull-out or jump-out load of the connection. The joint tensile breaking strength exhibited by physical testing is equal to the product of the ultimate strength and the critical section area of the specimen being tested. Jump-out is a connection failure by disengagement of the threads which occurs before breaking (parting) of the pinwall. Failure by thread jump-out initiates at the engaged pin thread nearest the end of the coupling. The material yielding due to high axial tension plus the radial strains at the thread load flank (due to Poisson's effect) acts to separate pin and coupling. The disengagement of the first engaged pin thread starts a chain reaction through the remaining engaged threads and complete separation of the connection. Jump-out prior to pin wall breaking (parting) may be prevented if the engaged thread length plus large thread height relative to the pin (upset or not) thickness and coupling diameter are both great enough. Other than tensile breaking or jump-out, thread shear may be conceived as another possibility of the connection failure under axial tension. In reality, however, experience has shown that failure by thread shear does not occur. For quick comparisons of the connection tensile strength with the pipe body, tensile efficiency is often used. Tensile efficiency is a ration of the minimum critical section area of the connection to the nominal section area of the pipe. For final accuracy, however, it is obvious from the above discussion that the connection tensile strength should be used rather than the tensile efficiency.

The structural failure modes associated with uniaxial influence of internal and external pressures of casing and tubing string are burst and collapse, respectively, of the pipe of connector wall. Coupled connections have greater wall thickness (pin plus box) than the pipe body and, consequenctly, the failures would occur not in the connection, but in the pipe body. On the other hand, the opposite is possible for the string with flush connections unless the connection bow thickness is expanded by cold-forming. Failure of a structural member can be either functional or structural.

A structural failure usually implies a functional failure, but a functional failure does not necessarily imply a structural failure. For instance, a tubing connection leak under internal pressure combined with tension is considered as a functional failure unless the leakage results from fracturing in the connection. The permanent corkscrewing associated with the helical buckling of the tubing is also considered to be a functional failure because the buckling is not accompanied with excessive bending deformation leading to the pipe wall wrinkling. Therefore, the connection subjected to axial compression should be able to maintain not structural integrity, but leak tightness under the bending resulting from the helical buckling.

5. 2 Leak Resistance (Tightness)

5. 2. 1 Seal Forces

The basic law of physics that must be complied with, if a joint is required to be leak resistant, is that the two sealing elements of the connection must be in intimate contact to such a degree that the interference force (unit bearing pressure) will always be equal to or greater than the pressure differential across the joint. This means that the leak resistance of a joint is directly related to the amount of interference and the structural strength of the mechanism to retain this interference as internal/external pressure is applied. In general, if a pin member of a joint is made-up with interference, causing permanent radial distortion, that member can only recover radially an amount equivalent to the resilient until the resiliency is spent. Therefore, the structural strength of the coupling is more important than that of the pin member to retain interference contact between the coupling and pin elements throughout the application of varied internal pressure.

When two cylindrical members are assembled by a shrink fit (having a common axis) and then subjected to either or both internal and external pressure, the unit bearing force at the interface will be increased as the pressure increases. If we consider the joint to have internal pressure only, then the interference force will increase with the increase of internal pressure, but at a slower rate than the rate of increase of internal pressure. Because of resulting radial strains, this will continue unitl a point is reached where the internal member no longer has any remaining hoop compression of the original shrink fit. At this instant, the internal pressure and the interference force at the interface are equal. This is the critical pressure above which the interference force would have to be less than the applied pressure.

5. 2. 2 Galling

Galling resistance of two interference surfaces is essential for connection leak tightness. Galling is a form of adhesive wear which involves junction welding of two metallic surfaces and subsequent shearing of the weld junctions, resulting in the characteristic gouged surface topographies on one of the surfaces. When a joint is made-up with interference, two mated members may slide some considerable distance. The distant sliding and the interference force induce galling. High frictional sliding reactions result in galling between two metallic members. If the sliding distance is short, galling may not occur.

When quenched and tempered, or high alloy (CRA) pipe is used, a special (deburring) finishing treatment is a minimum requirement for resisting galling. Natural galling resistance of connections on normalized carbon steel tubulars is forfeited when quenched. In order to resist galling, connectors must be specifically finished and carefully handled and run. One finishing technique is fine sand or glass bead blasting of corrosion resistant alloys (CRA) or tumble blasting of alloy steels. Coatings also help connections to resist galling. Alloy steels are usually phosphated with a chemical conversion coating. CRA's are often copper plated. Slow turning of assemblies (1"3rmp) is necessary for high alloys. API modified thread compound may be used for galling resistance. However, it must be well mixed and clean (free of sand or grit).

5. 3 Low Assembly Stress

Low connection assembly stress is required where sulphide stress corrosion cracking (SSCC) is expected. SSCC results from sour production at temperatures below about 150°*F*. SSCC, in which cracks develop in the material, requires high tensile stress in the presence of hydrogen. Connections that perform well in SSCC service usually exhibit low tensile stresses across the box connector section during assembly. Connection makeup could impart high tensile circumferential (hoop) stresses in the box (coupling) of tapered, interference threads.

5. 4 Damage Resistance

The connection should be resistant to damage including wear or galling from multiple makeup and breakout of the joint since tubing strings may be repeatedly pulled from the well to perform various operations such as workover, fracing, squeezing, acidizing, drilling bridge plugs, etc.

5. 5 Quick and Easy Makeup

The connection must be quick and easy to makeup for faster running time to save rig time.

5. 6 Adaptability

The connection must be adaptable for field repairs and for cross-over connections.

5. 7 Smooth Connection ID Transition

The internal profile of the connection should be sufficiently smooth to prevent erosion/corrosion. When the blow velocity (and entrained solids) become significant enough to wash out connections due to cavitation or flow erosion, greater consideration must be given to eliminating the recess in the coupling at the end of the pins. Many connections with an internal shoulder are recess-free. Recess-free joints will further reduce the tendency for wax to deposit.

5. 8 Corrosion Resistance

Corrosion may be caused by the presence of either H_2S or CO_2 (or a combination of both) and depends upon concentrations in the gas. H_2S corrosion, or sour corrosion, occurs in two special forms, i.e., sulphide stress corrosion cracking (SSCC) and hydrogen embrittlement, in which hydrogen atoms enter the lattice structure of the steel, thereby embrittling it. In addition, sour corrosion may cause general weight loss of the material. CO_2 corrosion, or sweet corrosion, usually manifest itself in the form of pitting and ringworm corrosion. H_2S weight-loss corrosion is aggravated by turbulence. To combat this, internally streamlined recess-free connection are recommended. When CO_2 corrosion is a prblem, the use of internally streamlined recess-free joints is recommended to combat pitting corrosion. The use of inhibitor remains necessary against all types of weight-loss corrosion.

6. Conclusion

OCTG casing tubing connections are not like the ordinary household and bolts. Failure of the connections during their service lifetime can incur significant loss of time and money. Furthermore, the associated safety problem can be very crucial. Therefore, the connections require precision in the design and manufacturing and special care in subsequent handling, transportation and field running of the connections. The author hopes that the above information could provide the reader a state-of-the-art knowledge about the connections.

◇

★ NEWS ★

7th International Conference on Pressure Vessel Teechnology

주　　관 : German Committee of the International Council for Pressure Vessel Technology
기　　간 : 1992년 5월 31일－6월 5일(6일간)
개 최 지 : Hotel Hilton International in Dusseldorf, Federal Republic of Germany
분　　야 : Group A : Design and Stress Analysis of Pressure Vessel, Piping, Fitting and Special Components
Group B : Material and Manufacturing of Components
Group C : Experimental Studies, Operating Experiences and Failure Analysis
Group D : Quality Assurance, Non-Destructive Testing, Inspection
일　　정 : 1990년 8월 31일　　초록 접수마감(약 300단어)
1991년 6월 30일　　채택 여부통보
1991년 10월 31일　　논문제출마감
연 락 처 : THE ASIAN AND OCEANIC REGIONAL COMMITTEE OF THE ICPVT
Prof. K. Iida, Department of Mechanical Engineering, Shubaura Institute of Technology, 3-9-14, Shibaura, Minato-ko, Tokyo, Japan(FAX 81-489-78-7796)

★ 기타 상세한 사항은 홍익대학교 표동근교수에게 문의바람.
Tel. (02) 334-0951 교환 523, FAX. (02) 333-6445