Modelling and Finite Element Analysis of Double Ferrule Fitting

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Abstract— Double ferrule fittings are widely used for connecting tube subjected to high pressure hence are designed precisely. There are no standards available for fixing dimensions of ferrule fittings hence it is optimized by carrying experimentation and Finite Element Analysis. As the designing of ferrule fitting starts by considering material properties, outer diameter and thickness of pipe, so in this case study is carried out for pipe material SS316, 1 inch outer diameter with wall thickness of 0.066 inch. Analytical methods are described and used to convey the means of sealing mechanism, via metal to metal mechanical face seal, or static seal. The fitting is modeled by referring to patents available and dimension is fixed with proper judgement keeping with consideration to swaging and sealing action. Solid modelling and assembly is done using CAD software SOLIDWORKS 2014. A geometric and material non-linear finite element simulation using ANSYS R15.0 is conducted to show the real life behavior of swaging mechanism and stress distribution in double ferrule fittings. The DoE for performance analysis, optimization and hydraulic burst using FE simulation is in process.

Index Terms— ANSYS, compression fittings, ferrule, Swaging, SS316

I. INTRODUCTION

High pressure couplings are couplings are typically manufactured for use in the hydraulics, oil and gas, chemical, and nuclear industries. They provide a suitable sealing interface minimizing the leakage rate whilst maintaining fluid viscosity, both minimizing flow resistance and maintaining the average laminar/turbulent fluid flow. Due to the seal mechanism it is important to ensure material compatibility at the interface between the ferrule and joining pipe in order to have corrosion resistance and to avoid galvanic corrosion. The basic Double Ferrule Tube Fittings is a four piece Fitting consisting of the Nut, the Back Ferrule, the Front Ferrule and the Body. When installed, it becomes a five piece connection with the addition of the tubing providing a solid leak free joint as shown in Fig. 1. [8]

The major advantage of this fitting is it only swages the surface of the tube and does not penetrate into it which maintains the tube strength.

A. Ferrule Functionality

The device comprises a body having a passageway there through to receive a cylindrical elongated male member such as a tube. The passageway has a tapered mouth providing an annular camming surface against which a generally frusto-conical annular ferrule is adapted to be fitted over the cylindrical tube. A flanged annular back ferrule, adapted to be fitted over the cylindrical member rearward of the front ferrule has a forward generally frusto-conical end portion received within an annular tapered camming-mouth which is provided at the provided at the rear end of the front ferrule. A coupling nut is threaded upon the body, is utilized to drive the back ferrule against the tapered mouth of the front ferrule and, by force transmitted through the back ferrule, to drive the front ferrule into the tapered mouth of the body. As the ferrules are driven forwardly, they move along the surfaces of the tapered mouths and are cammed radially inwardly against the external surface of the male member. The movement of the ferrules swages the surface of the male member into a gentle pattern forming annular ridges and valleys which prevent withdrawal of the male member from the body [2] as shown in Fig. 2. Swaging of tube

Fig 2. Swaging of tube

At the same time, the wedging action of both the ferrules tightly between the surface of the male member and the surfaces of the respective tapered mouths forms a seal effective against extremely high pressures, vibration and ultra-high vacuums as well. The correctness of the time sequence relationship between the various progressive phases of front and back ferrule movement is indispensable to optimum gripping and sealing. [2]- [3]
B. Failure Mechanism

As explained above by tightening of the nut, ferrule swages onto the pipe by causing a homogeneous indentation radially. It is expected that if the nut is not tightened adequately upon installation a resultant overpressure, or possibly nominal pressure, may cause the pipe to work axially along the fitting until it bypasses the ferrule, at which point leakage will occur. The range of possible causes of failure specific to compression couplings is extensive and can include,

- Incorrect fitting – ferrule placement, under-torquing the nut or over tightening it.
- Excessive pressure or water hammer.
- Pressure transient and/or vibrations.
- Thermal cycling (hot or cold).
- Material defect
- Inadequate design
- Service life exceeded or bad condition of fitting.
- Post bending of the pipe. After the coupling has been installed the pipe may be bent to fit it into place; this will produce lateral (radial) loading.
- Incorrect pipe preparation – the pipe must be cut square to sit in the fitting body.

II. LITERATURE REVIEW

Leonard P. Spontelli invented the apparatus for swaging and testing of ferrule fitting. The apparatus includes hydraulic actuated camming surface for engaging the ferrules and forcing them radially inwardly into engagement with the tube forming swaging of the tube to prevent longitudinal movement of the ferrules. Additionally, testing means are provided for testing the integrity of the swaging operation to determine whether or not the tube will move relative to the ferrules. [1]

Fred A. Lennon, Chagrin Falls, and Emery J. Zahnranec invented a controlled phase sequential gripping device namely double ferrule fitting which is used here as the base of design. [2]

Changxiang Xu, researched a tube fitting with either single or double ferrule swage design common in one system. The invention is about providing tube swage connection design with two coordinate tube-swaging motions which are separated and in succession, not interfered with and different from each other; using the smooth-swaging motion realizes the sealing connection and using the depression-swaging motion realizes the fastening connection. [3]

Peter C. Williams, Howard C. B. Kuhns further improved the tube fitting performance. High localized loading, galling, and high torque forces have been generally eliminated or greatly reduced in a two ferrule tube fitting assembly through suitable modification of the rear ferrule so as to redirect the reaction forces acting between the front ferrule and the drive nut. They have also proposed different shapes or configuration of back ferrule and modified interface surface between nut and the back ferrule. [4]

Gerhard H. Schiroky, Peter C. Williams and Michael W. Jones invention provides ferrules manufactured from hollow cylindrical stock, such as welded hollow cylindrical stock and processes for making such ferrules. [5]

Peter C. Williams and Steven V. Marx provided method for entire case hardening the surface of stainless steel back ferrule by carburization method without the formation of carbides. The concept of case hardening is to transform a relatively thin layer of material at the surface of the part by diffusion of carbon or other ingredients to make the surface harder than the base metal alloy. The invention is not limited to stainless steel, it is applicable to many types of chromium based bearing ferrous or nickel based alloy. [6]

Peter C. Williams and Steven V. Marx again invented the method for selective case hardening by low temperature carburization which includes the steps of applying a carbon blocking mask over the entire surface areas of the back ferrule that are not going to be carburized; exposing those surface areas only that are to be carburized; diffusing carbon into the exposed surface areas at a temperature below at which carbides readily form thereby removing the carbon blocking mask. [7]

III. THEORY AND APPROACH

A. Analytical Engineering

The sealing mechanism however occurs at a microscopic level, as a function of the contact between the interfering parts i.e. between two ferrules and pipe. If two bodies are in contact as Fig. 3 and a force, F, is exchanged normal to the tangent of the origin, O, so that two points, m and n, touch (as per Fig. 4), then the distance m and n have travelled vertically, called w1 and w2 [10], can be described by

$$w_1 + w_2 = \left( \frac{1 - v^2}{E} + \frac{1 - v'^2}{E'} \right) \frac{q}{r}$$

where v and E are poisons ratio and elastic modulus.

Fig. 3 Two contacting bodies with point’s m and n before contact.
The applied force, F, is described above as the intensity of the uniformly distributed load across the contacting surfaces, \( q_c \). Other subscripts denote the material properties of the two bodies, and \( dA \) is an infinitesimal area of the contact surface.

The above equation was initially solved by H. Hertz as [11],

\[
q_c = \frac{1.5F}{r_a r_b}
\]

Where, \( r_a \) and \( r_b \) are the major and minor radii of the semi-ellipsoid; and the maximum contact pressure (Hertzian contact pressure), \( q_c \), acts at the center of the contact surface.

**B. Modelling**

The solid modelling and assembly of fitting is done using SOLIDWORKS 2014. The double ferrule fitting in application has following major parts- pipe, coupling nut, back ferrule, front ferrule and body. First the tube dimension are fixed based on the pressure requirement. The basic dimension based on tube outer diameter was obtained from manufacturer’s catalogue. The pipe is assumed to be perfectly straight without any defects. The body have internal recess to restrict the pipe from further advancement. The coupling have internal threads which engages with the external threads of the body. The coupling nut have tapered surface which is in contact with the rear end of back ferrule. The front end of the front ferrule is in contact with the frusto-conical mouth of the body whose included angle varies from 300 to 580. The front ferrule has conical shape whose axial length is greater than length of the back ferrule also the included angle of front ferrule is 100 less than that of the body [2]. The back ferrule has stepped surface and its length is half as that of the front ferrule. The fitting is modelled in such a way that it has self-aligning feature.

**C. Material Selection**

Material selection for the fitting is based on the pressure and working environment. The entire fitting must be manufactured using same material as that of the pipe to avoid galvanic corrosion. As the pipe used in the fitting is suppose have lowest hardness of all so its elastic modulus was input as 100Gpa whereas the back ferrule is one whose entire surface is case hardened, hence it has highest stiffness compared to other parts of assembly so elastic modulus was input as 250Gpa. The nut, front ferrule and body have nearly same hardness so they have elastic modulus 200Gpa. The other properties common for entire fitting assembly are poisons ratio = 0.33, coefficient of friction = 0.557. The generalized plasticity curve for SS316 is shown in Fig. 7.

**D. Boundary Conditions**

The independent variable that defines the sealing mechanism is the torque applied to the nut, which places a linear transformation onto the ferrule, compressing it. Hence, the mechanical interactions between the four parts are paramount to an accurate simulation.

Defining the contact region is important in this case as there will be relative motion sliding and sticking between different parts, contact defined are shown in Fig. 9. The frictional contacts are defined with coefficient of friction of 0.557.
For complete tightening of the nut it is recommended and observed from practice that the nut should be rotated by one and quarter turn for getting the perfect sealing. From this the displacement of the nut and used as boundary condition. For single start threads with pitch of 1.27 mm

Displacement for one and quarter turn = 1.25*1.27 = 1.587mm

Further the coupling body is fixed as shown in Fig. 10.

The back ferrule and front ferrule are mesh using quadrilateral elements since those are perfect circular parts. A non-linear model with fine meshing leads to convergence as shown in Fig. 11. [9]

IV. RESULTS & DISCUSSION

The correctness of the time sequence relationship between the various phases of front and back ferrule movement is verified by FA result. As stated in the patented application [2] and observed in actual that the front ferrule should accomplish most of its forward and inward motion before the contraction of the back ferrule begins this action is clearly seen in FE simulation by referring Fig. 12 and Fig. 13.

The complete deformation of ferrules and pipe is shown in Fig 14. It is seen that the tip of the front ferrule penetrates between the body and the pipe but does not bite the pipe hence give better sealing and fatigue resistance. The back ferrule holds the front ferrule and also provides vibration resistance.

V. PROPOSED FUTURE SCOPE

i) The current computational model studies the sealing mechanism of a compression fitting. It does not however model the method of leakage, and as such it follows that the next logical step would be to couple the ANSYS model with that of a CFD model, also burst test can be conducted in FE simulation.

ii) FE simulation could be carried out for different shapes of ferrule as suggested in patents to suggest its influence. This is however more suggestive of a re-design approach.

iii) Case hardening property can be applied to back ferrule such that its core has the lesser hardness than the thin layer at surface.

iv) Design of Experimentation can be carried out in ANSYS Design Exploration by parametrizing the most influencing parameter like geometry, material etc. of the ferrule from which regression equations and response
surface can be obtained for more detailed understanding of performance.

REFERENCES


