

螺旋钢管残余应力分析研究

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摘要 螺旋钢管因其制造工艺成熟、成本较低, 是流体输送管道主要使用的一种钢管。目前普遍采用连续成型、埋弧焊接的方法制造螺旋钢管。成型方法有内承式和外抱式两种。由于这两种成型方法一般都是不足量成型, 钢管制造后有很大的残余应力, 降低了钢管的承压能力。经过理论分析, 给出了不足量成型时钢管的残余应力计算公式, 并通过实际测量内承式成型的螺旋钢管的残余应力, 验证了本文给出的残余应力计算公式的正确性, 对螺旋钢管的制造与应用具有指导作用。

关键词 螺旋钢管 成型方法 残余应力 弹复量

螺旋焊钢管在石油化工、热力管网及城市给排水工程等领域有广泛的应用, 尤其在长距离输送石油、天然气管道中更普遍采用。油田、气田管网几乎全部采用螺旋焊钢管, 具有很高的安全性、耐用性及经济合理性。由于螺旋焊钢管的管径一般不受板材宽度的限制, 可由多种不同规格的板宽卷板制造, 因此不需要宽板幅的钢板。这样给板材制造、运输带来方便, 所使用的带钢比平板钢价格要低得多, 适合我国实际情况。螺旋焊钢管存在的一个问题是焊后钢管产生弹复, 相当于钢管预先承受一个周向拉应力, 该应力会产生应力腐蚀和降低钢管的承压能力。因此, 如何评价钢管焊接后内应力的存在, 消除制造中产生的周向拉应力, 允许钢管周向开口量是需要解决的实际问题。本文对目前国内外普遍采用的螺旋焊钢管成型方法进行了分析, 给出了弹复量、内应力与钢管参数之间的定量关系。

1 螺旋钢管成型方法与内应力产生原因

螺旋焊钢管采用连续成型、焊接的方法制造, 目前普遍采用的是内承式和外抱式两种成型方法, 成型原理如图 1。

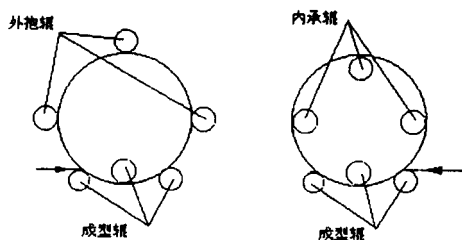


图 1 螺旋钢管成型原理

成型辊与内承辊 (或外抱辊) 组成一个成型器,

钢板沿图中箭头所示方向送入成型器中, 一边成型一边焊接。通过调整成型器可以获得不同规格尺寸的钢管。为防止过量弯曲, 三个成型辊与钢板接触点的高度一般不能相差太大, 厂家都采用不足量成型, 钢管曲率半径是依靠内承辊 (或外抱辊) 所形成的曲率半径保证, 在内承辊 (或外抱辊) 中钢板实际上是弹性和塑性混合变形。焊接后的螺旋钢管沿母线方向剖开后, 必然存在着一定周向开口量, 即钢管存在着一定的弹复量, 钢管存在着残余内应力。由于内应力的存在, 钢管外部是拉应力, 因此, 这会降低钢管的承压能力, 加剧钢管外部的应力腐蚀, 给钢管的使用带来不利影响。

许多文献都详细讨论了调型参数 (成型辊位置参数) 对钢管弹复量的影响, 但由于实际受整个焊机组参数及钢板参数的影响, 也只能进行不精确的定量分析。实际上目前各个螺旋钢管生产厂家都依靠经验, 大概调整成型辊位置参数, 然后生产一段钢管, 沿母线将钢管剖开, 检查其开口量是否达到客户要求。对于不十分重要的钢管 (如自来水管) 则对钢管开口量不限制。但国外对螺旋钢管的开口量一般都有严格限制, 其根本原因就是保证钢管在使用中的安全性, 虽然我国有些管线用的螺旋钢管开口量也提出了类似要求, 但其具体数值与内应力关系究竟如何则不清楚, 下面讨论这方面关系。

2 弹复量与最大内应力的关系

假设钢管成型时的曲率半径是完全依靠内承辊 (或外抱辊) 所保证的, 即钢板弯曲的曲率半径等于内承辊 (或外抱辊) 所形成的曲率半径。钢管开口前、后如图 2。

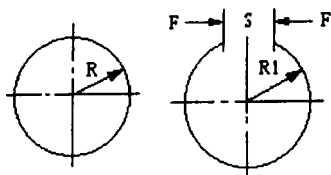


图 2 钢管开口前、后示意图

假设钢管开口后在外力 F 作用下重新闭合。材料由零曲率首先在一个假想弯矩 M_1 作用下, 弯曲到曲率半径 R_1 的圆, 然后当弯矩 M_1 继续增加到 M 时, 钢管曲率半径达到 R 。根据弯矩与曲率半径关系(弹性变形), 得到如下关系:

$$M_1 = \frac{EI}{R_1} \quad (1)$$

$$M = \frac{EI}{R} \quad (2)$$

其中: R_1 ——钢管弹复后的半径, m;

R ——钢管半径, m;

M_1 ——钢板由平直弯曲成半径为 R_1 时所承受的弯矩, $N \cdot m$;

M ——钢板由平直弯曲成 R 时所承受的弯矩, 单位 $N \cdot m$;

E ——材料弹性模量, N/m^2 ;

I ——钢板横截面的惯性积, m^4 。

则 M 与 M_1 的差值 ΔM 即为当钢管有开口量 S 时产生结构内应力的原因, 由 (1)、(2) 两式得 ΔM 的表达式为:

$$\Delta M = M - M_1 = EI \left(\frac{1}{R} - \frac{1}{R_1} \right) \quad (3)$$

又因为开口量的弧长与钢管周长相比较小, 且钢管弯曲曲率较小, 因此开口段钢管的弧长近似等于弦长, 则有下列关系式:

$$\begin{aligned} 2\pi R_1 &\approx 2\pi R + S \\ \frac{1}{R_1} &= \frac{2\pi}{2\pi R + S} \end{aligned} \quad (4)$$

将 (4) 式代入到 (3) 式, ΔM 的表达式可写为:

$$\Delta M = EI \left(\frac{1}{R} - \frac{2\pi}{2\pi R + S} \right) = \frac{EIS}{R(2\pi R + S)} \quad (5)$$

由于假设材料为弹性变形, 则最大内应力 σ_{\max} 与弯矩 ΔM 的关系为:

$$\Delta M = \frac{2\sigma_{\max} I}{h} \quad (6)$$

将 (5) 式代入到 (6) 式得:

$$\frac{2\sigma_{\max} I}{h} = \frac{EIS}{R(2\pi R + S)} \quad (7)$$

从 (7) 式得到 σ_{\max} 的表达式为:

$$\sigma_{\max} = \frac{ESh}{2R(2\pi R + S)} \quad (8)$$

其中: σ_{\max} ——钢管最大残余应力, Pa;

S ——钢管弹复后的开口量(弦长), m;

h ——钢管壁厚, m_0 。

3 结论验证

式 (8) 给出了螺旋钢管由于不足量成型产生残余内应力的具体表达式, 可见内应力的大小与材料弹性模量、半径、厚度及开口量都有关系。实际生产中由于厂家这些量是可以测量的, 因此由 (8) 式完全可以定量地衡量不同规格、不同材质的螺旋钢管内应力对使用的影响。文[5]给出了一种规格的螺旋钢管具体的测量值, 具体测量数据与计算结果见表 1。

表 1 测量数值与计算数值(钢管规格: $\Phi 426 \times 7$; 材质: SM41B)

| 测量点 | 测量点与焊缝位置 | 弹复量 (mm) | 测量值 (MPa) | 计算值 (MPa) | 误差 |
|-----|----------|-------------|--------------|--------------|-------|
| 1 | 内90° | 134 | 336.1 | 324.3 | 3.5% |
| 2 | 内180° | | 380.8 | | 14.8% |
| 3 | 外90° | | 275.6 | | 17.7% |
| 4 | 外180° | | 325.2 | | 0.3% |

从表中可见, 误差最小为 0.3%, 最大为 17.7%。由于实际钢板在成型焊接过程中要经过开卷、校形、切割等工序, 同时钢板在轧制过程中不均匀, 这些因素都能使钢板平面的力学性能和尺寸参数不可能处处均匀, 导致成型时钢管在圆周方向弯曲程度是不一样的, 所以测量值与计算值存在偏差是必然的。但从误差值来看是不大的, 说明本文给出的公式可以用来定量地计算螺旋钢管开口量所造成的附加内应力。另外由于在公式推导过程中认为开口段的弦长等于弧长, 计算应力值要小于实际测量值, 这一点从表 1 中可以看出。本文推导出的公式无论对螺旋钢管生产厂家, 还是对实际用户都具有十分重要的指导意义。

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Abstract & Key Words**Analysis of Creep Rupture Strength Test and Assessment of Service Life for Coking Tower**

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Abstract: The creep rupture strength test and safety analysis are made for a badly deformed coking tower with a long-time service under an elevated temperature. The result of analysis shows that the material properties of the coking tower has not deteriorated even though it has been used for a long time under the very bad conditions. Based on the estimation of its service life in this paper, it can still be used under the current operation conditions for ten years. Furthermore, a scientific evaluation of safety to the operation ahead of this coking tower is also provided.

Key words: coking tower, creep rupture strength, life estimation, safety analysis

Discussion on Reinforcement of Large Openings in Cylindrical Shells of Pressure Vessels

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Abstract: Because there is fewer calculation methods for the reinforcement of large openings in cylindrical shells in the old design codes, in addition, the pressure-area method is a easy method for calculation, so many designers generally use this method for the design of large openings. By making and analyzing a comparison between the calculation results that are based on the method in Appendix 1-7 of ASME Sec. VIII Div. 1, the finite element stress analysis and the pressure-area method respectively, it is indicated in this paper that the safety allowance of the calculation result based on the pressure area method is insufficient, and the calculation method in Appendix 1-7 of ASME Sec. VIII Div. 1 is safer and more reliable than the pressure area method. Therefore, it is proposed that the calculation method in Appendix 1-7 of ASME Sec. VIII Div. 1 can be absorbed and transformed into the professional standard of our country so as to provide a more reliable guarantee from the code to the calculation and design of the large radial openings in the cylindrical shells.

Key words: cylindrical shell, large opening, pressure-area method, Appendix 1-7 of ASME Sec. VIII Div. 1, finite element stress analysis

Design of Frame - Supported Columns

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Abstract: In this paper, the deflection at a top of the self-supported column under the wind loads is calculated by means of the superposition method based on the mechanics of materials, and the reacting force at the supporting place is determined through the analysis of the force acted on the frame-supported column, in which the rigidity values of the column itself and the supporting frame shall be adjusted and matched in order to limit the deflection at the top of column to an allowable range. This calculated reacting force is to be applied to the strength design of the frame-supported columns.

Key words: frame-supported column, deflection at a top of column, reacting force at the supporting place

Study on Reinforcement for Pipes with Brackets

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Abstract: The pipe with the brackets is commonly used in petrochemical enterprises. By means of the method of the FEA, the numerical value analysis to its stress state was made. The effect of the ring reinforcement on the stress distribution in the stress concentration region of the pipe was studied. And the influence of the dimensions of the reinforcing ring on the reinforcement effect was shown in this paper.

Key words: pipe with brackets, reinforcement, FEA (Finite Element Analysis)

ment Analysis)

Development of Wave - Serrated Metal and Flexible Graphite Covered Gasket Applied to Medium Pressure or High Pressure Steam Piping

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Abstract: It is introduced in this paper that the structural design of the wave-serrated metal and flexible graphite covered gasket applied to the medium pressure or high pressure steam piping and the effect on the performance indexes, the research of compound technology and the test of sealing performance. It is shown that this gasket has good performances in service and wide prospects for marketing.

Key Words: medium pressure or high pressure steam piping, wave-serrated metal and flexible graphite covered gasket, performance, development

Study on Classification Assessment Methodology of Safety Quality about Protective Coatings on Underground Steel Pipelines

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Abstract: For underground steel pipelines, the key point concerned by operators, inspectors and the related functional department in the government is the safety and quality status of the protective coatings on the underground steel pipelines. In this paper, the actual importance and necessity of the classification assessment for the coatings are mainly discussed. The present situation on the classification assessment methodology at home and abroad are summarized and the basic thinking on the classification assessment are stated. In addition, some classification assessment indexes are put forward. The several technical themes in the classification assessment methodology that need to be further studied and solved are presented in the paper.

Key words: underground steel pipeline, protective coating, safety quality, classification assessment methodology

Analysis and Assessment on Defects in Welds of Large - Diameter Steam Pipeline Made of Straight Seam Steel Pipes

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Abstract: The dissection for analyzing the defects in the welds in a large diameter pipeline (630 mm in diameter and 4500 meter long) made of the straight seam steel pipes was carried out. The conclusion that the flaws are welding cold cracks was made. Based on the principle of "fitness for use", allowable maximum sizes of the defects in both the longitudinal welds of the pipes and the circumferential welds in this pipeline were determined in accordance to the flaw evaluation code for pressure piping. And the defects failed to the acceptance criteria in this pipeline were assessed.

Key words: pressure pipeline, crack, defect assessment

Analysis and Research on Residual Stress in Spiral Seam Welded Steel Pipes

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Abstract: The spiral seam welded steel pipe is a main material of piping that are used for fluid service because of its mature fabrication process and lower cost. Now the continuous forming and SAW (submerged arc welding) methods are commonly used for fabricating the spiral seam welded steel pipes. There are two forming methods, the inner holding and the outer holding. Owing to the insufficient

forming that is ordinarily produced by adopting any of the two forming methods, there is the significant residual stress in the pipes after fabrication, which is to reduce the capability bearing pressure of the pipes. By theoretical analysis, the calculation formula for the residual stress in the pipes due to the insufficient forming was given in this paper. By comparison to the practical measurement of the residual stress in the one size of pipe formed by the inner holding method, the accuracy of the calculation formula for the residual stress given in this paper was verified. It has a guiding effect for the fabrication and application of the spiral seam welded steel pipes.

Key words: spiral seam welded steel pipe, forming method, residual stress, elastic resilience

Halfen Channels

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Abstract: In this paper, the advantages, models and functions about the Halfen Channels as well as its fitted anchor piece and fastening piece are introduced.

Key words: petrochemical production plant, process piping, embedded part, Halfen Channels, manufacturing localization

Flow Capacity & Surge Control for Centrifugal Compressors

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Abstract: Three methods of surge control for centrifugal compressors are outlined in this paper. And the details of three control methods, the suction throttle operating in constant speed, variable speed operating and inlet guide vane operating in constant speed, are respectively introduced and analyzed.

Key words: centrifugal compressor, flow capacity, surge control

Energy - Saving Process for Auxiliary Propane Refrigeration unit in Application to Natural Gas Cryogenic System

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Abstract: It is introduced in this paper that an energy - saving process for the auxiliary refrigeration unit with propane as refrigerant which is applied to the cryogenic system used for the natural gas. By analyzing the correlation between the selected stage number of the compressor and the needed power consumption for compression, the optimum scheme for determining the stage number of the compressor is put forward.

Key Words: propane refrigeration, energy - saving process, stage number

Circulating Technology of Oil System for Turbo - Generator Set

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Abstract: By the analysis on the factors which affect the flushing effect of oil - circulation, some methods for speeding up the speed of oil circulating and raising the quality of oil circulation were put forward in this paper. The methods are to take a great difference in temperature of the circulating oil by fast - heating and fast - cooling, to fill the dry compressed air into the circulating oil continuously and to separate the whole oil system into the several subsystems with the flashing of oil circulation under the condition of greater flow velocity. The operating time and cost were reduced by using these methods.

Key words: turbo - generator, oil system, analysis, measure

Modification of Decarbonating Solution Pump for Capacity Increase

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Abstract: By modifying the impeller structure of the centrifugal pump, the capacity was increased, the head was raised and, therefore, the requirements in production were satisfied.

Key Words: centrifugal pump, modification, capacity, increase

Failure Analysis and Improvement about Worm Wheel in Turbine for Condensate Pump

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Abstract: The cause for the failure of the worm wheel in the turbine used for driving the condensate pump was analyzed. By changing the material of the worm wheel from the tin bronze (ZQSn10 - 1) into the beryllium bronze (QBe1. 7), the good result of improvement was gained.

Key Words: turbine, worm wheel, failure analysis, improvement

Research and Manufacturing of Sliding - Vane Viscous Oil Pump

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Abstract: In comparison with the screw pump or cam pump, the type HLBN36 / 1. 2 of sliding - vane viscous oil pump has the advantages such as its compact structure, smooth and steady running, high efficiency and low noise etc. . Therefore, it can be widely applied to the fields of lubricant, crude oil, chemical industry, food and pharmaceutical industries etc. . In this paper, the principle, structural characteristics, technical innovation and testing circumstances etc. of this slide - vane viscous oil pump were introduced.

Key Words: sliding - vane pump, viscous oil pump, design, test

Inspection and Analysis on Tubes in Coking Heater

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Abstract: By a comprehensive inspection to the tubes used in the coking heater in service, the certain defects in the tubes were discovered and the deterioration of material quality has not taken place yet. These tubes can still be in the operation under the present conditions for a long time. The improvement proposal on selection of the material applied to the tubes for the heater in the high temperature service was put forward.

Key words: tube in coking heater, inspection, analysis

Damage and Repair of Carbon Steel Shell in Storage Tank of Medium Pressure Decomposing Separator

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Abstract: It was briefly introduced that the damage state of the shell in the storage tank of the medium pressure decomposing separator which was caused by corrosion. The solution of it was put forward in this paper.

Key Words: medium pressure decomposing separator, carbon steel shell, corrosion, overlay clad welding

Calculation about Installation Dimension and Material Preparing Measurement of Nozzles in Vessels

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Abstract: If the nozzles connected with flanges are attached to the shell or head of a vessel by the welded connections, the installation related dimensions and the corresponding measurements for the material preparation of the nozzles shall be indicated in the assembly drawing of the vessel in accordance to the design requirement. For easy to make the design and installation, it is mainly introduced in this paper that the method of calculation about the projecting length of the nozzles from the shell or heads of vessels

Key Words: vessel, nozzle, dimension related to installation, measurement for material preparation