

第三代涡识别方法 在液力变矩器空化流场中的适用性分析

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摘要 | 液力变矩器中涡空化的产生和发展严重影响其内流场及外特性,尤其在极端工况下。精细识别液力变矩器内流场非定常多尺度三维涡结构和提取涡空化空间结构特征是目前研究的热点问题。基于计算流体力学,采用应力混合涡模型对液力变矩器空化流场进行高精度数值模拟,基于第二代和第三代涡识别技术选取 Q 准则和 Ω 方法,两种典型的涡识别方法对液力变矩器流道内部空化涡结构进行三维重构,分析低速比工况下各叶片表面空化特征动态演化规律并重点研究导轮叶片处空化现象。研究表明:Q 准则阈值选择盲目性大,难以同时识别到空化流场中的强涡与弱涡结构; Ω 方法能够在较大阈值范围内精确地辨识空化流场涡结构;制动工况下导轮内空化现象最为严重。

关键词: 液力变矩器; 内流场; 空化; 涡识别

液力变矩器依靠流体传动实现能量的传递与转换,是传动系统中的关键核心部件,在工程机械及汽车领域应用广泛^[1]。液力变矩器的工作性能由其内部湍流特性决定,其内部流场是具有多种尺度不一和强度各异的涡结构,这些涡对湍流的生成和发展起着关键作用^[2]。极端工况下出现的空化现象会导致流场结构恶化,涡结构更加复杂。精细地识别液力变矩器空化流场中涡结构的时空演化特征,对于分析并揭示液力变矩器空化流场演化规律及能量损耗机理具有重要的研究意义。

目前,对于液力变矩器空化流场的分析已不局限于压力、速度及涡量等常规物理参数。流场的非定常效应导致各参数处于不断变化之中,这些参数无法精确地揭示

空化流场演化规律。随着涡识别技术的发展,对空化流场旋涡特征进行精确提取成为可能,并诞生了多种涡识别方法。第二代涡识别方法中最具代表性的 Q 准则得到了广泛的应用并取得初步效果^[3]。但第二代涡识别方法存在一定的缺陷,且物理意义并不清晰,受阈值等因素的影响,无法确定合适的等值面来代表涡结构,难以同时捕捉空化流场内三维涡结构的全貌。针对涡识别准则存在的问题,德州大学阿灵顿分校刘超群教授及其团队开展了一系列工作,提出 Ω 涡识别方法即第三代涡识别准则^[4]。新的方法物理意义清晰,能够准确提取出层流转捩过程中的涡核中心线结构。同时,该方法阈值选择范围具有归一化(取值范围为 0~1)的特点。国内外学者对液力变矩器

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内流场涡结构提取方面做了大量研究,但基于第三代涡识别方法提取液力变矩器空化流场中内部涡结构鲜见报道,该方法填补了一直以来难以快捷地选择出合适阈值来识别液力变矩器流道内部涡结构的空白。

本文基于计算流体力学,采用应力混合涡湍流模型数值模拟液力变矩器不同工况下空化旋涡流场,采用Q准则和 Ω 方法分别提取空化流场三维涡结构特征,针对空化流场涡系重构效果、涡识别阈值范围选择及其敏感性分析,研究了第三代涡识别方法提取液力变矩器空化流场涡结构的适用性。

1 研究对象

1.1 计算模型

本文选用的是扁平化冲焊型液力变矩器,其循环圆有效直径为236 mm,泵轮叶片数为37,涡轮叶片数为31,导轮叶片数为28,3个叶轮叶片都是冲压而成,其中泵轮叶片和涡轮叶片表面均有加强筋,以此来提高叶栅强度。为简化计算,提取叶片叶形曲线,经布尔操作提取液力变矩器流道模型,忽略各叶轮之间间隙导致的液压油泄漏及温度变化对油黏度的影响,只考虑液力变矩器3个叶轮所组成的封闭的耦合区域作为计算域。液力变矩器叶栅结构及流道模型如图1所示。

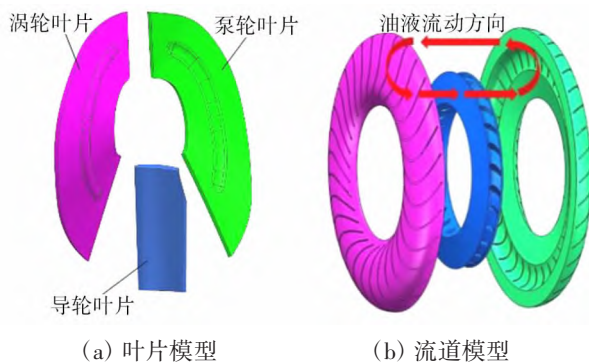


图1 液力变矩器叶栅结构及流道模型

1.2 网格模型

本文选取的液力变矩器是应用在汽车当中的,受变速器轴向尺寸的限制导致液力变矩器腔型扁平化,因此在装配时,导轮叶片出口靠近内环处与泵轮发生干涉,由

于泵轮是冲压而成,导轮是铸造而成,考虑到冲压磨具成本较高,故改进导轮叶片结构来达到装配目的。改进后的模型经布尔操作提取全流道模型,导轮流道由于叶片结构的改进使得导轮叶片出口与interface面的空间过于狭小,经过反复尝试无法生成高质量的六面体网格。经综合考虑,采用ICEM流体网格划分软件,选取适用性较强的四面体非结构化网格填充液力变矩器全流道流体计算域,如图2所示。

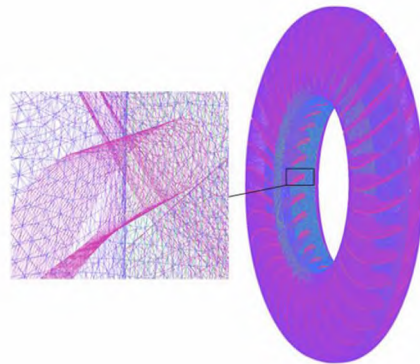


图2 网格模型

2 数值模拟方法

2.1 控制方程

液力变矩器空化流场是一种复杂的两相流动,假设流体为密度可变的单相流体,且混合物之间存在对流,采用均相流模型模拟空化流动过程,对连续性方程和动量守恒方程进行求解^[5]。

混合相连续性方程为:

$$\frac{\partial \rho_m}{\partial t} + \frac{\partial (\rho_m u_j)}{\partial x_j} = 0 \quad (1)$$

混合相动量守恒方程为:

$$\frac{\partial}{\partial t} (\rho_m u_i) + \frac{\partial}{\partial t} (\rho_m u_i u_j) = - \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[(\alpha_v + \alpha_g) \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2\partial u_k}{3\partial x_k} \delta_{ij} \right) \right] \quad (2)$$

式中: α_v 和 α_g 分别为蒸汽相体积分数和不可凝结气体的体积分数; ρ_m 为混合相密度,kg/m³。

2.2 湍流模型

采用应力混合涡湍流模型(SBES)对液力变矩器空化

流场进行数值模拟。在近壁面以耗散为主的边界层区域采用 SST $k-\omega$ 模型来进行处理,在主流区采用 LES 方法处理,本文在主流区选取 LES 方法中 WMLES 亚格子模型进行处理。SST $k-\omega$ 模型控制方程如式(3)和式(4)所示,WMLES 数学模型如式(5)所示。

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[(\mu + \sigma_k \mu) \frac{\partial k}{\partial x_i} \right] + \bar{P}_k - \beta^* \rho k \omega \quad (3)$$

$$\frac{\partial(\rho \omega)}{\partial t} + \frac{\partial(\rho \omega u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[(\mu + \sigma_\omega \mu) \frac{\partial \omega}{\partial x_i} \right] - \beta \rho \omega^2 +$$

$$2(1 - F_1) \rho \sigma_{\omega 2} \frac{1}{\omega} \frac{\partial k}{\partial x_i} \frac{\partial \omega}{\partial x_i} + \alpha \rho S^2$$

WMLES^[6]模型为克服雷诺数的尺度限制而提出,湍动黏度 μ_t 定义为:

$$\mu_t = (C_{Smag} \Delta)^2 S \{ 1 - \exp[-(y^+ / 25)^3] \} \quad (5)$$

式中: C_{Smag} 为模型系数。

SBES 对 SST 的 k 方程进行重构,添加了汇项 ε_{SBES} , 其定义为:

$$\varepsilon_{SBES} = -\beta^* \rho k \omega F_{SBES} \quad (6)$$

$$F_{SBES} = \left[\max \left(\frac{L_t}{C_{SBES} \Delta_{SBES}}, 1 \right) - 1 \right] \quad (7)$$

在主流区切换至 WMLES 方法后,为使切换过程中湍黏性在切换前后匹配一致,定义 μ_t 为:

$$\mu_t = [0.286 2 C_{WMLES} \Delta]^2 S \quad (8)$$

式中: C_{WMLES} 为 WMLES 模型中的常数; S 为应变率; Δ 为网格大小。

同时,还需利用混合函数将 SST 模型和 WMLES 模型中的应力项结合起来,可通过下式进行^[7]:

$$\tau_{ij}^{SBES} = f_{SBES} \tau_{ij}^{SST} + (1 - f_{SBES}) \tau_{ij}^{WMLES} \quad (9)$$

式中: τ_{ij}^{SST} 和 τ_{ij}^{WMLES} 分别为 SST 模型及 WMLES 模型的应力张量; τ_{ij}^{SBES} 为 SBES 模型的应力张量。

2.3 空化模型

Schnerr- Sauer 模型基于 Rayleigh- Plesset 单气泡动力学方程,气相质量变化率与气相体积分数变化率之间的关系为:

$$\frac{\partial u_j}{\partial x_j} = \frac{\rho_v \rho_0}{\rho_m} \frac{d\alpha_v}{dt} \quad (10)$$

气相体积分数 α_v 变化率与气泡半径 R_B 变化率之间的关系为:

$$\frac{d\alpha_v}{dt} = \alpha_v (1 - \alpha_v) \frac{3}{R_B} \frac{dR_B}{dt} \quad (11)$$

单位体积相间的质量传输方程为:

$$R = \frac{\partial(\alpha_v \rho_v)}{\partial t} + \frac{\partial(\alpha_v \rho_v u_j)}{\partial x_j} = \frac{\rho_v \rho_0}{\rho_m} \frac{d\alpha_v}{dt} \quad (12)$$

Schnerr- Sauer 空化模型^[8]的最终表达式为:

$$\begin{cases} R_c = \frac{3\alpha_v (1 - \alpha_v)}{R_B} \frac{\rho_0 \rho_v}{\rho_m} \sqrt{\frac{2}{3} \frac{(p - p_v)}{\rho_0}}, & p < p_v \\ R_c = \frac{3\alpha_v (1 - \alpha_v)}{R_B} \frac{\rho_0 \rho_v}{\rho_m} \sqrt{\frac{2}{3} \frac{(p - p_v)}{\rho_0}}, & p \geq p_v \end{cases} \quad (13)$$

2.4 涡识别方法

2.4.1 Q 准则

Hunt^[9]等将速度梯度张量 $\nabla \mathbf{V}$ 分解为对称张量 \mathbf{A} 和反对称张量 \mathbf{B} ,使用速度梯度张量 $\nabla \mathbf{V}$ 的第 2 个伽利略不变量 $Q > 0$ 代表涡结构,对称张量 \mathbf{A} 有抵消反对称张量 \mathbf{B} 旋转的效果,因此 Q 的物理意义在于反对称张量 \mathbf{B} 要能克服对称张量 \mathbf{A} 所代表的抵消效果,表达式可以通过 Cauchy- Stokes 分解写为:

$$Q = \frac{1}{2} (\| \mathbf{B} \|_F^2 - \| \mathbf{A} \|_F^2) \quad (14)$$

式中: $\| \cdot \|_F$ 为矩阵的 Frobenius 范数; Q 的单位为 s^{-2} 。

2.4.2 Ω 方法

刘超群^[10]等基于涡量理论提出 Ω 方法,涡量实际上并不能代表流体的旋转,因此将涡量 ω 分解为旋转部分和非旋转部分,即:

$$\omega = R + S \quad (15)$$

式中: R 为旋转部分的涡量; S 为非旋转部分的涡量,即纯剪切。

由于非旋转部分涡量的存在,导致 R 和 ω 方向不同,因此,引入一个参数 Ω ,代表旋转部分涡量大小占总涡量大小的比例。刘超群提出的估算 Ω 公式为:

$$\Omega = \frac{\|B\|_F^2}{\|A\|_F^2 + \|B\|_F^2} \quad (16)$$

为了防止零除的问题,在式(16)的分母项上引入一个小的正数 ε , Ω 表达式变为:

$$\Omega = \frac{\|B\|_F^2}{\|A\|_F^2 + \|B\|_F^2 + \varepsilon} \quad (17)$$

Ω 取值范围为 $0 \leq \Omega \leq 1$, 代表涡量浓度, 即流体刚性, 当阈值大于 0.5 时, 表示反对称张量 B 相对于对称张量 A 占优, 可以取阈值略大于 0.5 来作为涡识别的判据, 当 $\Omega=1$ 时, 代表流体做刚体旋转^[4]。

2.5 流场计算设置

基于 Fluent 软件采用 Mixture 多相流模型进行数值模拟。为保证计算结果与实际情况吻合, 近壁面采用滑移边界条件, 采用 8 号液力传动油作为流动介质, 不考虑温升对油液参数的影响, 设置液相密度为 860 kg/m^3 , 黏度为 $0.0258 \text{ Pa}\cdot\text{s}$, 气相密度为 2.1 kg/m^3 , 饱和蒸汽压为 110 Pa , 时间步长为 $1 \times 10^{-3} \text{ s}$ 。固定泵轮转速 $n_p=2000 \text{ r/min}$, 采用 SBES 湍流模型与 S-S 空化模型组合形式进行仿真分析。

3 空化流场涡结构辨析及阈值选择

3.1 空化流场涡结构辨识

制动工况下, 涡轮静止不动, 泵轮带动油液高速旋转, 此时腔体内循环流量最大。在扭曲叶片的作用下, 导致油液局部流速梯度变大, 引起局部压力下降, 此时压力低于饱和蒸汽压, 油液中析出了大量气泡, 流场发生激变, 在随着油液流动气泡进入到高压区域时, 这些气泡重新凝聚为液体, 造成了局部真空, 在压力差的作用下周围的流体迅速填补真空区, 流体质点的相互作用产生了复杂的涡结构。基于 Q 准则、 Ω 方法提取制动工况下液力变矩器空化流场内部三维涡结构, 如图 3 所示。为了详细对比分析两种涡识别方法的差异性, 本文单独截取了泵轮流道局部放大图。从整体涡结构提取效果来看, 2 种涡识别方法都能呈现出空化流场内部三维涡结构的复杂多

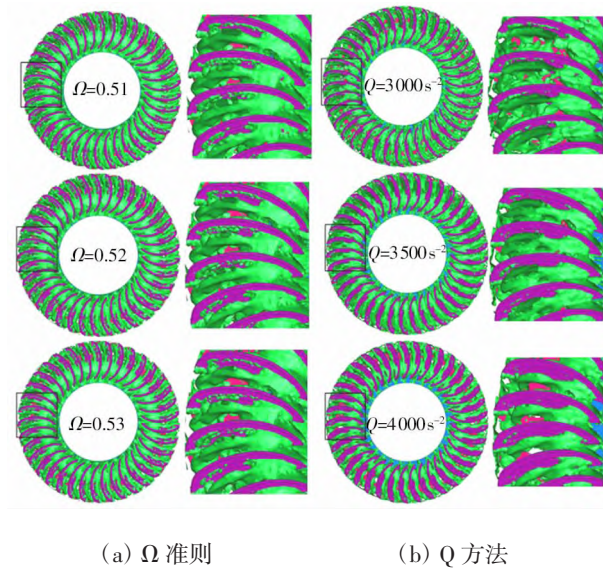


图 3 不同涡识别方法提取的三维涡结构

变性的。但是, 从局部涡结构提取效果来看, 2 种方法呈现了明显的差异性, Ω 方法能将流体旋转运动和剪切运动区分开来, 在泵轮流道内捕捉到清晰的长条涡结构。Q 方法内存在剪切污染, 涡的结构层次不够分明, 错误地将剪切层识别为涡结构, 无法精确捕捉到长条涡及多尺度涡结构特征, 难以建立涡结构与空化流场之间的关联。

3.2 阈值敏感性分析

涡结构的识别效果与阈值的选择息息相关, 本文针对 Q 准则和 Ω 方法分别选取了 3 个阈值, 所提取的三维涡结构如图 3 所示。由图 3 可见: 采用 Q 准则, 选取不同的 Q 值会呈现出不同的涡形态, 当 Q 取 3000 s^{-2} 时, 涡的分布较密且涡结构破碎相互分离, 无法精确区分涡的形态及不同涡之间的相互作用, 随着 Q 的取值变大, 部分涡结构上的流动信息缺失严重, 无法解析空化流场的复杂流动现象; 采用 Ω 方法, Ω 取 0.51 时, 涡的结构及分布能很好地展示出流体的流动情况及流动结构对动量能量输运方程的表征, 随着 Ω 的取值变大, 涡的整体变化趋势不大, 涡系结构仍较为完整。

综上所述, 由于第二代涡识别方法 Q 准则在理论上具有先天的不足, 受阈值范围选择的敏感性影响程度最

大,采用不同的阈值识别涡结构特征结果的差异性极其明显,且涡是流体绕当地轴的旋转运动,是具有方向性的,Q准则无法给出旋转方向。新提出的第三代涡识别 Ω 方法物理意义清晰,多尺度涡的拉伸、挤压、破碎、合并等物理作用较为明显,并能同时捕捉到强涡与弱涡,涡系结构完整,实现了归一化。对于本文的液力变矩器空化流场, Ω 方法选择阈值范围在0.51~0.53时,对于阈值范围选择的依赖性较弱,选择阈值为0.51时,三维空间多尺度涡系结构特征提取信息最为丰富。

4 空化结构特征提取及机理解析

4.1 空化结构特征识别

为了精确地解析制动工况下液力变矩器内流场空化发生的位置,以体积分数为10%的气泡等势面将空化发生的位置可视化,图4展示了制动工况下液力变矩器各叶片附近出现空化的具体位置和空间形态分布。由图4可以明显看出,气泡主要集中在导轮头部吸力面一侧,泵轮入口和涡轮入口也有少许气泡产生。制动工况下,由于涡轮静止不动,涡轮叶片的结构高度扭曲,流体沿着涡轮叶片以扬抛的形式高速流出,并以大入射角冲击导轮头部,经过导轮头部分离点后,液流分别沿着叶片的吸力面和压力面流动。导轮头部是一种变曲率的圆弧形,流体在冲击时局部形成圆柱绕流,流体受到离心力的作用导致导轮叶片头部压力骤降,若压力无限趋近于流体饱和蒸汽压力时,液体中分离出气泡,产生空化现象。此后导轮吸力面一侧曲率变大,叶形逐渐平滑,离心力逐渐消失,压力就不断上升。在压力面上,由于压力面一直受到液流冲击,压力面压力一直高于吸力面压力,不会发生空化现

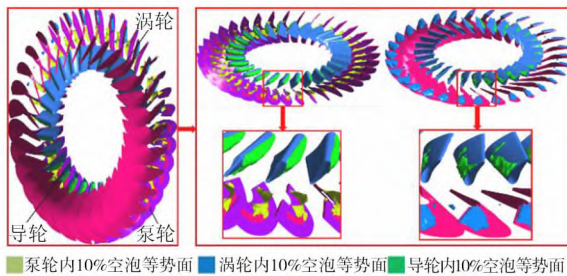


图4 制动工况下10%气泡体积分布等势面

象。在泵轮入口处有少许气泡产生,这是由于导轮尾部回射流引起流场激变而引起气泡不稳定进而脱落,并向下游运动,在泵轮流道内由于压力升高,气泡在泵轮叶片入口接近1/3处发生破灭,周而复始进入下一循环流动。

4.2 不同工况下空化特征演变

由于液力变矩器主要在车辆起步时工作,车辆正常运转时,锁止离合器启动,泵轮与涡轮刚性连接,此时液力变矩器不工作,因此本文主要对低速比几个典型工况进行研究。

图5分别呈现了泵轮、涡轮、导轮叶片空化现象随转速比变化的时空演化规律。制动工况下,液力变矩器循环流量及油液速度达到峰值,导致流腔内局部压力最低,空

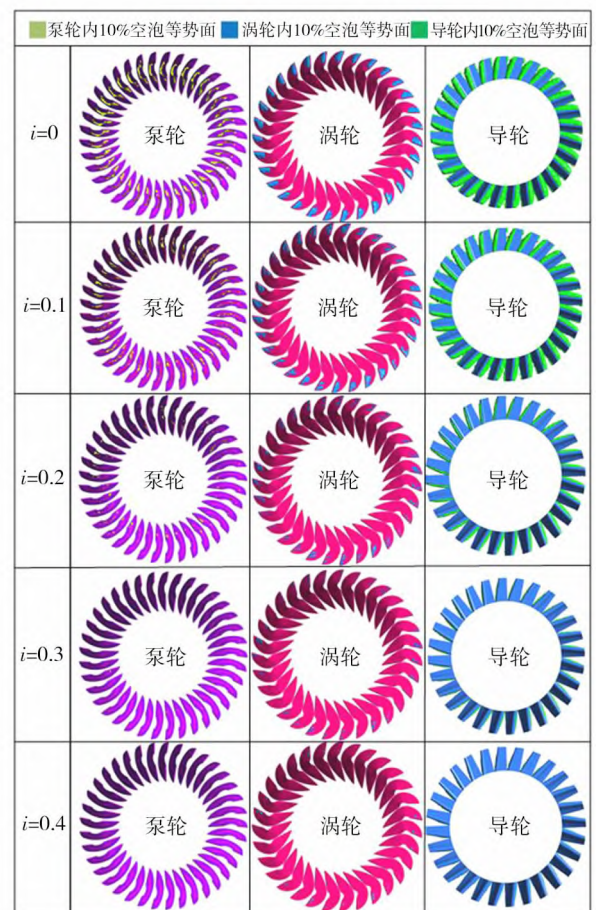


图5 不同工况下10%气泡体积分布等势面

化现象特征最明显,不仅导轮内分布着较多空泡,泵轮和涡轮吸力面上也分布着附着空泡。随着转速比提高,气泡空间分布体积逐渐缩减,直至转速比 $i=0.4$ 工况,空化现象几乎完全消失殆尽,这是由于随着转速比升高,涡轮转速逐渐攀升,总的循环流量减少而引起速度降低,压力值逐渐回升,因此气泡分布越来越少。

4.3 导轮空化机理分析

考虑到导轮一般为铸造而成,加工成本较低,研究导轮内空化产生机理,对导轮叶形进行多目标优化来提高液力变矩器工作效率是一种可行的方法。图6展示了导轮区域内空泡分布与压力的对应关系,根据空化类型分类,该导轮内流动区域上主要分布着附着空化和剪切层空化。当没有考虑空化时,导轮头部存在明显的负压,这是由于涡轮流出的高速流体以较大的入射角冲击导轮头部,导轮头部由于圆弧过渡而形成圆柱绕流。在靠近导轮内环出口处也有少量空泡析出,这是由于启动工况下,导轮内空化流动极为不稳定所引起的。在不考虑空化时,导

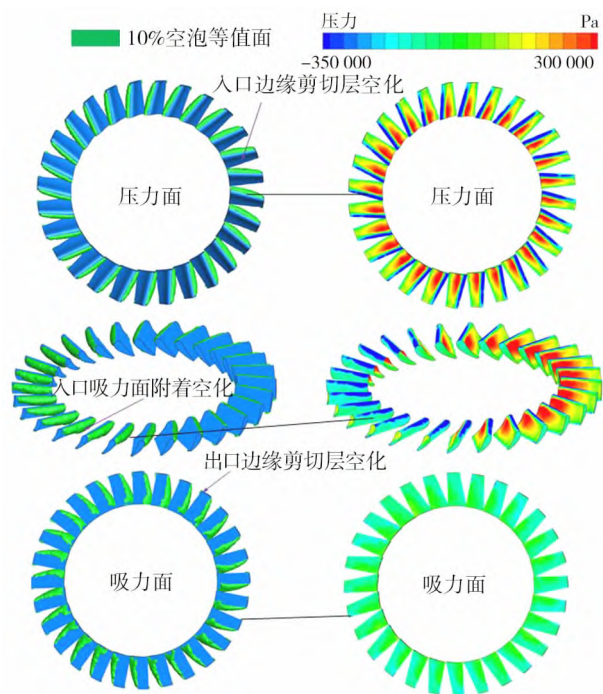


图6 压力的分布与空泡位置对比

轮内部的负压区和空化时气泡分布的位置刚好吻合,因此可以通过压力数值模拟结果来预测空化发生的概率。

4.4 涡空化时空演化特性分析

通过后处理技术对空化区域进行三维重构,结果表明,启动工况下在导轮和涡轮中观察到严重的空化现象,泵轮中检测到少量空化。这是由于从涡轮中流出的流体以较大的入射角撞击导轮叶片,导致前缘附近的吸力面上出现局部高速低压区,并在下游产生较大的逆流。为了详细分析导轮内空化时空演化规律,本文提取了一个周期内导轮空化区域的变化历程。

如图7所示,以10%空泡等值面的分布和发展说明制动工况下导轮区域的空化过程。首先,在 $t=T/4$ 时,导轮吸力面进口处靠近内环附近形成附着空化,随着空化的发展,附着空化沿着内环到外环生长,且高度升高,近似圆锥形,从而加剧其空化不稳定性,此时各叶轮的转矩出现明显的波动。导轮空化的发生由循环流量和入射角决定,当循环流量接近空化起始阈值时,液力变矩器中会出现附着空化。随着质量流量的增加,空化变得不稳定,由反向压力梯度驱动的重入射流向导轮移动。由于该型号液力变矩器循环圆直径较小,循环流量不足以触发导轮内空泡发生明显脱落现象。

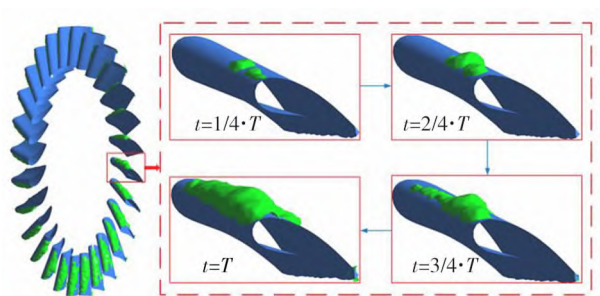


图7 制动工况下导轮区域非定常空化过程

由于较高的入射角和高流速,在启动工况下,涡轮入口吸力面上也可观察到空化区域。为展示制动工况下涡轮流道空泡随时间的周期性变化,图8以10%空泡等值面的分布和发展说明制动工况下涡轮区域的空化过程。在一个周期内,首先,在 $t=T/4$ 时,涡轮入口吸力面上靠近外环处的剪切层出现空泡,随着流速的提高导致低压区

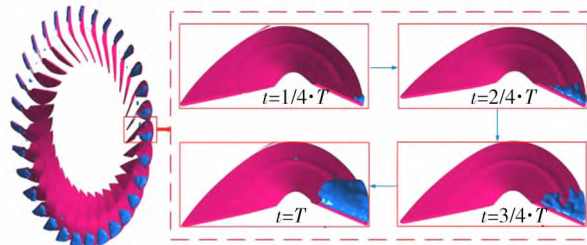


图8 制动工况下涡轮区域非稳态空化过程

域变大,空泡开始从外环到内环沿着吸力面生长,此时涡轮内形成的空化类型为片状空化,在 $t=T$ 时,空泡不再增长,达到一个稳定状态,未观察到气泡脱落现象。

5 结论

本文研究了第二代和第三代涡识别方法的理论基础,并将其应用在液力变矩器空化流场中,所得研究结论主要有:

(1) 在空化流场结构特征辨识上, Q 准则识别效果受阈值选择影响较大,盲目性强,存在先天的不足; Ω 方法可在较大的阈值范围内识别涡结构,对空化流场中多尺度涡捕捉能力较强,能同时捕捉到强涡和弱涡,不受阈值限制。

(2) 从空化流场结构特征识别与提取上发现,制动工况下的空化现象最为明显,导轮叶片头部是空化发生的高发区,泵轮入口与涡轮入口处也有少许空化产生,随着转速比的提升空化现象逐渐消失。

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Keywords: Hydro-pneumatic suspension; Adams/Car; Simulation; Optimization

Structural Optimization Design and Simulation of Shield Body of Earth Pressure Balance Shield

Based on the geological data of South Extension Bid 2 project of Shenyang Metro Line 2, the load distribution characteristics of water and soil on the surface of the shield body are obtained by separate calculation of water and soil. Based on the load analysis and equipment functional requirements, the three-dimensional structure framework of the shield body is built, and the strength and stiffness of the shield body structure under various working conditions are analyzed through finite element simulation to obtain the equivalent stress and displacement nephograms of the shield body, to clarify the weak points in the designed structure and to optimize the design accordingly. The results show that, 1) the earth pressure and friction force on the shield body are symmetrically distributed along the longitudinal section of the tunnel, and their values tend to decrease first and then increase in the range of 0 to 180°; 2) the diameter of the shield body is designed in a stepped layout, and the configuration of advanced grouting interface, shield body radial lubrication system and pressure-bearing spacer interface can effectively improve the safety and efficiency of shield construction; 3) the shield body runs smoothly throughout the construction process with tiny deformation, which verifies the rationality of the shield body design and the feasibility of the finite

element simulation analysis method.

Keywords: Earth pressure balance shield; Shield body; Structural optimization design; Load analysis; Finite element simulation

Mechanical Structure Design of Push-plate Type and Rocker-flap Type Combined Wave Maker

The wave maker is an important test facility to simulate the impact of actual waves on ships or offshore buildings. Nowadays, the push-plate type wave maker and rocker-flap type wave maker are used on a large scale. However, the motion modes of these two wave makers are relatively monotonous, which cannot fully meet the test requirements. Combining the characteristics of the two types of wave makers and improving them and replacing the ball screw structure of the traditional wave maker with a linkage, a new push-plate type and rocker-flap type combined wave maker is designed. Firstly, based on the micro-amplitude wave theory, the working performance and design of the push-plate type wave maker and rocker-flap type wave maker are calculated, and the parameters that meet the working performance and design of the push-plate type wave maker and rocker-flap type wave maker are analyzed and derived. Then, the parameters of the transmission mechanism are calculated. Finally, the three-dimensional drawing of the wave maker is drawn by using SolidWorks according to the obtained parameters.

Keywords: Wave maker; Linkage; Micro-amplitude wave theory; Push-plate type and rocker-flap type combined

Development and Application of Torque Converter with Large Torque and Capacity

The application of low-speed engine in the hydraulic transmission system puts forward higher requirements for the input characteristics of the torque converter, so the torque converter needs greater load characteristics. For the hydraulic-drive large-tonnage roller matched with a low-speed engine, the applicable three-element centripetal torque converter with a turbine structure and large torque and capacity is developed. On the premise of satisfying the overall dynamic property, the matching research on the fuel economy of the engine and the torque converter is carried out, and the original characteristics of the torque converter are designed. The results of the bench test of the torque converter and the performance test of the whole vehicle show that all the indicators of the developed torque converter with large torque and capacity have reached the theoretical design target, and compared with the common models, the roller equipped with a low-speed electronically controlled engine and a large-torque-capacity torque converter has a comprehensive fuel saving of 10% and a noise reduction of 2 dB.

Keywords: Torque converter; Large torque; Energy conservation and consumption reduction

Applicability Analysis of Third Generation of Vortex Identification Method in Cavitation Flow Field of Torque Converter

The generation and development of vortex cavitation in the torque converter seriously affects its internal flow field and external

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characteristics, especially under extreme operating conditions. Precise identification of the unsteady multi-scale three-dimensional vortex structure of the internal flow field of the torque converter and extraction of the spatial structure characteristics of the vortex cavitation are the hot issues of current research. Based on computational fluid dynamics, the cavitation flow field of the torque converter is simulated numerically with a high accuracy by using a stress mixed vortex model, the Q criterion and method are selected based on the second and third generations of vortex identification technologies, two typical vortex identification methods are used to reconstruct the three-dimensional structure of the cavitation vortex in the flow field of the torque converter, the dynamic evolution law of the cavitation characteristics of the blade surface under the low speed ratio condition is analyzed, and the cavitation phenomenon at the guide wheel blade is emphatically studied. The results show that, the selection of Q criterion threshold is blind, and it is difficult to identify the strong and weak vortex structures in the cavitation flow field at the same time; the method can accurately identify the vortex structure of the cavitation flow field within a wide range of thresholds; the cavitation phenomenon in the guide wheel is the most serious under the braking condition.

Keywords: Torque converter; Internal flow field; Cavitation; Vortex identification

Research Status of Laser-arc Hybrid Welding of High-strength Plate Steel

Compared with traditional steel, high-strength steel has the characteristics of excellent ductility and toughness and high strength. High-strength plate steel has been widely used in various fields because of its excellent properties, while the traditional welding method for high-strength plate steel has been difficult to meet the development needs of various industries. As an efficient welding method, laser-arc hybrid welding has attracted great attention in the welding of high-strength plate steel in recent years. However, the interaction of numerous process parameters of laser-arc hybrid welding results in the difficulty of regulation and control, which seriously restricts the service performance of the welded joints of high-strength plate steel. For the different forms of groove design, the research status of laser-arc hybrid welding in the field of high-strength plate steel welding is summarized, and the application and development of laser-arc hybrid welding for high-strength plate steel are prospected.

Keywords: Laser-arc hybrid welding; Plate; High-strength steel; Groove form; Application status

Suggestions on Standard System Construction of Forklift Truck Safety and Green Development

From the two fields of safety and green development, the framework of standard system of forklift trucks is built, the problems existing in the construction of standard system of forklift trucks are analyzed, and suggestions are made. From

the four aspects of safety standards, green development standards, local standards and standard transformation and implementation gaps, Jiangsu Province's standard development and revision are analyzed, and detailed and reasonable suggestions for standard development and revision are made according to the priority of needs. Finally, six suggestions are made for the standardization of forklift trucks in Jiangsu Province to further promote the development of forklift truck standardization and improve the adaptability and competitiveness of forklift truck safety and green development standards.

Keywords: Forklift truck; Standard system; Safety; Green development; Suggestion

New Steel Segment Support System for Open TBM

Taking Urumqi-Yuli Tianshan Shengli Tunnel project in Xinjiang as the background, combined with the measures taken by the open full face tunnel boring machine(TBM) to cope with adverse strata, a new steel segment support system is designed. The structure and functions of this new steel segment support system are introduced in detail, and the application effect of the steel segment support technology in practical projects is summarized. Finally, the advantages of the steel segment support system are described, which can provide reference for the preliminary support design of similar TBM projects.

Keywords: Open TBM; Steel segment support system; Urumqi-Yuli project