

# 盘式钻头及其破岩机理\*

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**摘 要** 介绍了一种新型齿形结构的牙轮钻头——盘式钻头的结构特点、破岩机理以及国外(特别是前苏联)在盘式钻头方面所做的工作,包括破岩机理方面的研究、实验室和现场试验工作及其在生产实际中的使用情况。对盘式钻头的研究现状及其在目前生产中推广应用所存在的问题作了简要介绍。并对开展盘式钻头进一步研究的可行性和具体研究方向作了详细阐述。同时对开展盘式钻头研究的重要意义及盘式钻头将在我国石油勘探开发中的作用及应用前景作了阐述。

**主题词** 钻井 盘式钻头 破岩机理 发展趋势 研究

随着我国油气资源的开发,对钻井工具也提出了一些新的要求。虽然一些特殊钻头(金刚石钻头、PDC 钻头等)的出现,解决了部分复杂地层的钻井问题,但仍难以满足目前我国石油天然气钻探要求的需要。因此,研制一种既具有较长使用寿命,又能对付多种复杂地层且具有较高的机械钻速和较高机械进尺的新型钻头是目前石油天然气钻探中的重要任务之一。综合牙轮钻头的发展过程可以看出,虽然牙轮钻头的寿命有了大幅度提高,但由于近三十年来牙轮钻头在齿形结构上没有多大变化,而牙轮钻头的破岩效率与齿形结构有直接关系,因而牙轮钻头的机械钻速在一些特殊地层上没有多大提高。所以,要提高牙轮钻头在一些特殊地层和特殊环境下的机械钻速、钻井进尺,必须寻求新的齿形结构。盘式钻头就是一种全新齿形结构的牙轮钻头。

## 盘式钻头的发展概况

对盘式钻头的研究在国外已作过一些工作,前苏联对盘式钻头方面作了大量的研究工作。美国、英国在 60 年代后期也在盘式钻头方面作了一些工作。前苏联利用圆盘式破岩工具的最初尝试是在

1941 年完成的,但不成功。当时是采用盘式多级扩孔钻钻井通风孔,不成功的原因在于它们结构不完善,以及这种钻具与被钻岩石不适应。1949 年,美国使用特殊的三牙轮钻头作其冲击旋转钻井试验。这些钻头的特点在于:为了加强齿面,牙轮的保径齿圈制成截面为楔形的,一个齿紧挨一个齿的齿排列,而其余齿圈上的牙齿则用连续的环状凸棱代替。尽管这些试验的结果令人满意,但并没有关于继续在美国研究和将这种钻头用于实际钻井的报道。

1951 年,Д. Н. 克依色列夫在矿场条件下,试验过一个牙轮和两个牙轮,齿面为一排或几排连续齿圈的三牙轮钻头。使用这种钻头,达到了足够高的机械钻速,并能保持井径。而鞅靶石油钻井科研院对直径不同的、具有圆弧状接触面积的圆盘形齿进行了静压入破岩效果研究,制造了一批为数不多的 86K9T 型的盘式钻头,与当时的普通牙轮钻头相比,机械进尺有大幅度提高。

1968~ 1969 年,在右比雷夫石油天然气勘探公司、布如鲁克尔石油公司和伏尔加管理局的水力专业公司进行了小批量、四种类型规格的盘式钻头的矿场试验。这些试验证明,盘式钻头的进尺提高了 13%~ 40%,机械钻速提高了 30%~ 40%。

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不同规格类型的盘式钻头台架试验和工业试验结果都说明,与常规钻头相比,盘式钻头具有很大优越性。把这些钻头用于钻硬岩层,钻头进尺和机械钻速平均要增长 50%,并大大降低破岩过程中的能耗。当用盘式牙轮钻头钻井时,所出现的楔形齿圈的自锐现象,决定了这种钻头在使用总期限内会有高的破碎能力。

此后,他们针对在使用过程中出现的问题,诸如牙齿的磨损、轴承的寿命、齿面的强化等问题作了一些研究工作,并取得了一些成果。

在 1967~1970 年期间,他们研制了各种改型的直径分别为 145, 151, 190 和 214 mm 的盘式钻头,并作了台架试验和矿场试验。

通过多种方案的实验得到了盘式钻头在不同岩石条件下的最佳齿形参数,包括齿形、齿间距、齿形角、齿圈刃宽和齿圈间距。并得到以下结果:①在整个钻进过程中,盘式钻头的机械钻速高于常规钻头约 30%;②由于直径的磨损,常规牙轮钻头比盘式钻头报废早得多。例如,开钻后 130 min,常规钻头的直径就减小 5 mm。盘式钻头的直径在钻进结束时总共仅减小 1 mm;③机械钻速的提高和连续式楔形齿圈寿命的增加决定了盘式钻头钻井时钻头进尺的大大提高;④试验钻头扭矩的平均值约为常规钻头的  $\frac{1}{2}$ ,并且在钻进过程中变化不大,同时,常规钻头在钻进结束时的扭矩与其初始值相比,约增加两倍;⑤盘式钻头在整个钻进期间的高机械钻速和低扭矩导致了在用这种钻头破岩时能耗降低,盘式钻头钻进时的单位体积破碎功约为常规钻头的  $\frac{1}{3}$ 。

## 盘式钻头的结构特点

盘式钻头的主体结构与现有的三牙轮钻头相似,也是由牙轮和牙爪组成。盘式钻头可以是单牙轮、双牙轮或三牙轮组成,其主要特点是其齿形与现有的牙轮钻头不同,其齿面制成与牙轮母线垂直的圆环形连续齿圈,由于没有牙齿,且其齿形像盘形,因而称之为盘式钻头。但后来随着钻井条件和地层的变化,盘式钻头在结构上有很大变化。

## 盘式钻头的破岩机理

盘式钻头的破岩机理根本不同于常规的牙轮钻

头,它改变了与岩石的作用特点及其破碎机理。盘式钻头的连续楔形齿圈沿岩块滚辗时,要形成同心圆环式的岩石破碎。这些破碎环分散为单个的圆环形岩屑,其大小取决于齿圈间距及岩石的机械物理性质。由于井底的圆环状破碎,增加了机械钻速和减小破岩过程中的能耗。

根据对盘式三牙轮钻头在台架实验和矿场试验中的分析,盘式牙轮钻头与齿形牙轮钻头相比,具有以下特点:①由于接触压力增加,且连续作用于井底,使得破岩效率得以提高,从而提高了机械钻速和降低了破岩能耗;②由于不存在一个齿到另一个齿的滚动,所以减小了钻头扭矩;③因为钻头与岩石相互作用的动载减小到最低,所以提高了轴承和齿面的寿命;④由于取消了费工时的铣齿工序,所以大大简化了钻头的制造工艺,从而也降低了钻头成本。

综上所述,新型的盘式三牙轮钻头比常规牙轮钻头更具有发展潜力,更值得我们去研究。

## 盘式钻头研究方向

盘式钻头 1941 年在前苏联出现,并相继在美国、法国、英国等国家使用,当时的台架实验和现场实验的结果都显示出良好的前景,但今天却难以见到在钻井中运用。就其原因作者认为可能有以下几个方面:①由于当时牙轮钻头普遍性能较差,结构不太合理,使得盘式钻头的优越性得到充分体现,并得到广泛重视,而后又没有作更进一步研究,使其不能得到进一步完善,从而被其它产品取代;②由于当时牙轮钻头的轴承质量差,成为影响钻头寿命的决定性因素,所以盘式钻头的齿面磨损问题显得不很突出,其优良的破岩效率和工作性能深受用户欢迎;③随着硬质合金镶齿钻头的出现,大大提高了镶齿钻头的齿面强度,从而提高了钻头使用寿命,因而在全世界很快得到广泛应用,从而淡化了对盘式钻头的进一步研究;④随着金刚石等新材料在钻头中的应用,相继研制成功金刚石钻头和现在被人们看重的 PDC 钻头,这些钻头的研制成功解决了一些特殊钻井需要。

总而言之,盘式钻头在新材料、新工艺发展之后,没有用这些新材料、新工艺来改进盘式钻头结构和性能,因而逐渐被淘汰。

随着钻井技术的不断提高,钻井难度不断加大,

钻井环境的日趋恶劣,对钻井工艺技术及钻井设备都将提出更高的要求,对钻井用的主要钻井工具(钻头),将面临如何改进其性能和开发出具有更好性能的优质钻头,以满足目前油气资源开发的需要。现有的牙轮钻头以及其它钻头都难以满足目前油气资源开发的需求。将现代加工工艺技术,新材料技术,现代设计技术和计算机应用技术结合在一起,在原有盘式钻头的基础上研制出具有良好钻井性能,适应性强的盘式牙轮钻头是完全可行的。根据对以前研究资料的分析,结合现有技术和设备,要研制出具有良好性能的盘式钻头,主要应从以下几方面进行研究:

(1) 破岩机理研究

要研制出具有较高工作性能的盘式钻头,首先必须研究盘式钻头的破岩机理,找到盘式钻头在破碎机理上与现有钻头的差异,为进一步提高盘式钻头的破岩效率寻求新的途径。

(2) 寻找最佳齿形结构

钻头牙齿的结构对钻头的工作性能和破岩效率有直接影响,合理可靠的钻头牙齿结构将是决定整个钻头性能的关键。所以针对不同的钻井要求,确定盘式钻头的最佳齿形参数和齿形结构是研究盘式钻头的重要工作之一。

(3) 齿面强化工艺研究

随着新材料,新工艺在生产中的应用,使整个产品质量有大幅度提高。要使盘式钻头具有较好的工作性能和较长的使用寿命,提高盘式钻头的齿面强度,提高齿面的耐磨性是盘式钻头是否具有竞争力

的关键,也是盘式钻头面临的主要任务。

(4) 整体钻头性能的仿真分析

在对盘式钻头的研究中,预测盘式钻头在钻井过程中的工作性能是很重要的工作。通过实现对盘式钻头的工作行为的仿真分析,在钻头未制造出来之前就可以预测不同结构的盘式钻头在实际钻井中的性能,为进一步改进盘式钻头结构,优化盘式钻头设计提供依据。

(5) 新型盘式钻头结构的研究

随着加工技术的发展和各种强化工艺技术在生产中的成功应用,使我们能够实现对盘式钻头在整体结构上改进,如采用螺旋齿面代替盘式齿面等,可以在原有盘式钻头的结构基础上根据实际钻井需要设计出适合于多种工况的盘式钻头。从而进一步提高盘式钻头的应用范围,使得盘式钻头不仅适用于硬地层和极硬地层,而且能适用于其它复杂地层和一些特殊钻井工况的要求。

盘式钻头是一种全新齿面的牙轮钻头,具有独特的破岩机理和良好的工作性能。随着新材料,新工艺技术的发展及其在生产中的成功运用,为我们进一步改进盘式钻头的结构,提高盘式钻头工作性能,研制出适用于多种工况要求和各种特殊钻井需要的盘式牙轮钻头成为可能。可以相信,开展对盘式钻头破岩机理的研究将进一步提高我国钻头技术水平和钻头整体质量。

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第三次天然气汽车技术推广工作会在成都召开

中国石油天然气总公司第三次天然气汽车(NGV)技术推广工作会于 1997 年 12 月 8 日~ 11 日在成都市召开。国家科委,总公司科技局、装备局、技术监督局、多经局、北京天然气集输总公司,以及大庆、大港、华北、中原、江汉、四川、新疆、塔西南油田,重庆石油高等专科学校,华油天然气股份有限公司的领导和代表共 113 人出席了会议。科技局副局长、总公司汽车办公室主任孙宁作了“抓住机遇,形成规模,提高质量,保障安全,加快天然气汽车事业的发展”的重要讲话。科技局局长石宝珩作了充分肯定成绩,看到存在问题,好好总结经验的讲话,强调了发展 NGV 事业要有历史责任感、紧迫感,要讲科学,要有坚韧不拔的精神。大家相信,通过这次会议,定将大大加快 NGV 事业发展的步伐。

(王协琴)

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**ABSTRACT:**This paper gives a more systematic description on the structure and can-be-realized function of well site computer from the construction, real time application and non-real time application, based on the comprehensive analysis of domestic and foreign existing various computerized apply drilling technologies, well site computer centers and real-time systems. Well site computer system is no longer a simple drilling parameter apparatus or used for simply monitoring the general drilling operation process and for out-of-limit alarm. Its function has been progressively extended and it can be used for predicting and interpreting various complex situations arisen during drilling by comprehensively analyzing a lot of datum acquired both from the surface and underground. It can make the real time analysis and monitoring for each drilling operating mode and can also make various off-line non-real time analysis, design and calculation. The paper also gives the further extensible application function of wellsite computer system.

**SUBJECT HEADINGS:** Drilling, Well site, Computer system, Data acquisition, Real time, Prediction.

**Li Qi** ( *associate professor* ), born in 1963, graduated in drilling engineering from Southwest Petroleum Institute in 1983 and received his Master's degree in 1986. He is the winner of Sun Yueyi's "Excellent Youth Scientific and Technical Prize", and he is now engaged in teaching and scientific research work. Add: No. 18, east section of No. 2 Dianzi Road, Xi'an, Shanxi ( 710061 ), China Tel: (029) 8219584.

ANALYSIS OF TEST PARAMETERS AND THEIR NEW DETERMINATION METHOD

Tang Jun, Li Daofen and Lan Xia (Drilling and Production Technology Research Institute, Sichuan Petroleum Administration). *NAT UR. GAS IND.* v. 18, no. 1, pp. 48~ 52, 1/25/98. ( ISSN 1000- 0976; In Chinese)

**ABSTRACT:**In the course of the geological exploration, drilling and exploitation of oil and gas, the analysis and processing of the important characteristic parameters of technical indexes and quality indexes, such as drilling engineering parameters, drilling fluid property parameters, formation porosity, permeability and water saturation as well as oil and gas reserve, etc., are always involved. If the index limits of these parameters are analyzed and determined based on the experience or by standard de-

viation method, some concrete problems, such as deviation of index from practice or complication in analysis and calculation etc., are easy to be caused. For this, the distribution characteristics of the finite order test data of the parameters most in use and their effect on the analysis results are analyzed and the main factors determining the deviation range are expounded in this paper. On the basis of probability theory and statistical law, a simple mathematical model for calculating finite order statistics or testing observation parameters is derived and the reliability and feasibility of this analytical method is expounded.

**SUBJECT HEADINGS:** Drilling fluid, Testing, Parameter, Analysis, Method.

**Tang Jun** ( *engineer* ), was born in 1965 and graduated from Xi'an Petroleum Institute in 1988. He is now engaged in the research on drilling fluid and its technology. Add: Guanghan, Sichuan( 618300 ), China Tel: ( 028 ) 3324911 - 251330 or 251331.

DISK BIT AND ITS ROCK - BREAKING MECHANISM

Liu Qingyou, Wu Zhebing and Ma Dekun ( Bit Research Department of Southwest Petroleum Institute ). *NAT UR. GAS IND.* v. 18, no. 1, pp. 53~ 55, 1/25/ 98. ( ISSN 1000- 0976; In Chinese)

**ABSTRACT:**In this paper, the structural characteristics and rock-breaking mechanism of the disk bit—a kind of roller bit with new tooth structure are presented, the works done abroad especially in former USSR, for disk bit, including the rock-breaking mechanism research, the test in laboratory and at worksite and the situation of its use in production practice are introduced, the current research situation of disk bit and the problems existed in its application and dissemination are briefly presented, the feasibility for further research and the research trend for disk bit are expounded in detail, and the significance of disk bit research, the role of disk bit in the petroleum exploration and development in China and its application prospects are discussed also.

**SUBJECT HEADINGS:** Drilling, Disk bit, Rock breaking mechanism, Developing trend, Research.

**Liu Qingyou** is now studying for Doctor's degree in the Mechanism-Engineering Department of Southwest Petroleum Institute. He is mainly engaged in scientific research and teaching work related to the CAD, CAM and computer emulation of petroleum mechanism. Add: Nanchong, Sichuan( 637001 ), China

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## WELL TEST MODEL STUDY OF THE GAS WELLS IN TIGHT RESERVOIR WITH LOW PERMEABILITY

Feng Xi, Zhong Fuxun and Luo Tao (Geological Exploration and Development Research Institute of Sichuan Petroleum Administration). *NATURAL GAS IND.* v. 18, no. 1, pp. 56~ 59, 1/25/ 98. (ISSN 1000- 0976; **In Chinese**)

**ABSTRACT:** Through a monographic study on the special well test problems related to the gas wells in tight reservoir with low permeability, some knowledges have been obtained: (1) The resistance of gas flowing through tight and low-permeability reservoir is caused mainly by the hydration film at the small pore's throat; (2) only the pressure differential at the two sides of hydration film surface is high to a certain degree, can the gas break the resistance of hydration film and flow; (3) when the pressure gradient of the gas during flowing is low to a certain degree, the hydration film forms again and flowing stops. Based on above mentioned knowledges, a well test model has been set up with aim and the analytical solution of the model is acquired by power series solution method. The algorithm study for calculating well test standard curve is done and the characteristic response and changing law of this special flow mechanism on well test curve are summed up.

**SUBJECT HEADINGS:** Low permeability pools, Low velocity, Non-Darcy flow, Gas well, Well testing, Boundary condition, Laplace transform, Iteration.

**Feng Xi** (*senior engineer*), graduated in mathematics from Sichuan University. He is mainly engaged in the research on software for gas field development and well test. Add: No. 1, section 1, Fuqing Road, Chengdu, Sichuan (610051), China Tel: (028) 3324911- 215652.

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## CALCULATION OF WELL BORE TEMPERATURE DISTRIBUTION IN CONDENSATE GAS WELL

Zhu Dewu and He Hanping (Production Department of Drilling Research Institute, Ministry of Geology and Mineral Resources).

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**ABSTRACT:** The well bore temperature distribution in condensate gas well is indispensable for the node analysis and performance analysis for gas well. Based on the heat transfer principle, the formula for calculating well bore temperature distribution in condensate gas well is presented, the method acquiring the basic data for the temperature calculation is discussed and the effect law of gas output, water output, well depth and tubing diameter on wellhead temperature is analyzed. The temperature in a certain condensate gas well with a depth of 5 400 m has been calculated. The gas-oil ratio of this well is 3 000. The gas contains 2.3% H<sub>2</sub>S and 4% N<sub>2</sub>. The formation temperature is 134 °C. Through calculation, it is shown that the relative error between the temperature measured at well head and that calculated is 0.2% ~ 3.8%, being up to the engineering accuracy. The well temperature presents a nonlinear distribution with the depth and the well head temperature increases with the increase of the output and depth but decreases with the decrease of the tubing's diameter. This formula also applies to the calculation of temperature distribution in dry gas well, wet gas well and condensate gas well and the calculation precision accords with the demands of engineering accuracy.

**SUBJECT HEADINGS:** Gas well, Condensate gas well, Temperature, Vertical tube flow well, Calculation method.

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## GETTING OUT A NEW WAY OF HIGH-QUALITY, HIGH-SPEED, HIGH-LEVEL AND HIGH-BENEFIT IN SHAAN-JING GAS PIPELINE CONSTRUCTION

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**ABSTRACT:** The Shaan-Jing gas pipeline engineering was constructed by the China National Petroleum Corporation and