进入地球深处的技术：全新研发的深井钻机海瑞克 Terra Invader 350（TI－350）系列产品

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在德国，为了有效地开发地热能源，地下钻井已达到2500到5000米的深度，从技术的角度而言，也更加具有挑战性。目前，对地热能源开发采用的仍是在石油及天然气行业中使用的传统钻探设备。然而，这些钻探设备已不能充分适应不断向地球更深处开发地热能源的要求。大钩载荷介于250和450吨之间的钻探设备特别适用于深井钻进。然而，这种规模的设备目前几乎已经在德国甚至欧洲市场绝迹了。针对地热能源行业新的需求，于2005年，海瑞克股份公司（Herrenknecht AG）成立了子公司 Herrenknecht Vertical GmbH。子公司开发了 Terra Invader 350 深井钻机系列产品，这是一种半自动化的深井钻机，大钩载荷达350吨，不仅能满足传统的陆地钻机施工要求，还满足于地热能源项目的特殊施工要求。当前关于气候变化的讨论以及开发可再生能源的迫切需求促使德国联邦环境、自然保护与核能安全部将该项目提升为德国联邦政府能源研究规划的一部分。

TI－350 系列是基于已有的石油、天然气以及深井钻探设备，积累了在之前地热能源项目知识和经验的基础上研发出来的。Herrenknecht Vertical GmbH 公司在产品的自动化、节能、设备工地安装的灵活性、设备的能源供给、减少噪音以及设备系统的一体化等领域做了进一步的研发和改进。以下是典型地热能源项目的相关介绍。

1　钻井施工场地

地热能源的开发必须靠近用户，也就是说，钻机必须能够在密集的建筑群区域进行作业。而我公司开发的 TI－350 产品井架需要的空间只有 9 m × 10 m。而且在钻塔周围钻机各部件的定位也十分灵活，这样整个钻机所需要空间只有 30 m × 80 m，另外，其余空间还可以进行优化利用。钻探施工场地的规模足够进行约 52 m 高，370 吨重的 TI－350 设备的组装和拆卸。

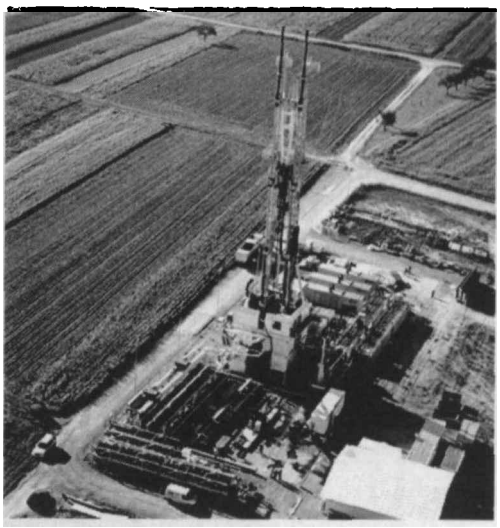


图 1　TI－350 施工现场的占地面积仅为 30 m × 80 m

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2 噪音防护措施

与油井相比，地热钻井需要在靠近用户的地方进行，以保证地热能的有效利用。因此，在开发 TI－350 设备时，特别强调了全面的噪音防护措施。一体化的噪音防护系统使设备能直接在商业区和住宅区附近进行钻井作业。设备能严格遵守其发出的噪音音量一直低于所要求的最大限度。噪音防护措施包括封闭式泥浆泵、最优化排气噪音抑制以及排气管布置的发电机以及带脉动阻尼的液压油缸起重设备等。这些措施的运用降低了钻机周围 150 m 范围内的噪音排放，其发出的噪音甚至低于一台低音量的电视机或者收音机。不论是钻机的操作人员，还是附近的居民，均可从这些噪音防护措施中受益。

3 能　效

一种综合的电能管理理念被应用于 TI－350，以改善在地热能源项目中整体能源的平衡。深井钻机可以采用不同的电力供给方式，公共电网供电或者市面上可提供的发电机供电均可，这样可以减少在附近区域的排放。电能只是在确实需要的情况下才提供。大部分的电能——大约 80%，供给于泥浆泵以运送钻探出的物料。为保持一定的流量，所需泥浆泵的压力取决于钻杆的内径。（钻杆）内径越大，压力损失越低，因此也就越节约电能。为了节约电能和成本，TI－350 深井钻机甚至可以配备大至 6⅝″的超大直径钻杆进行作业。

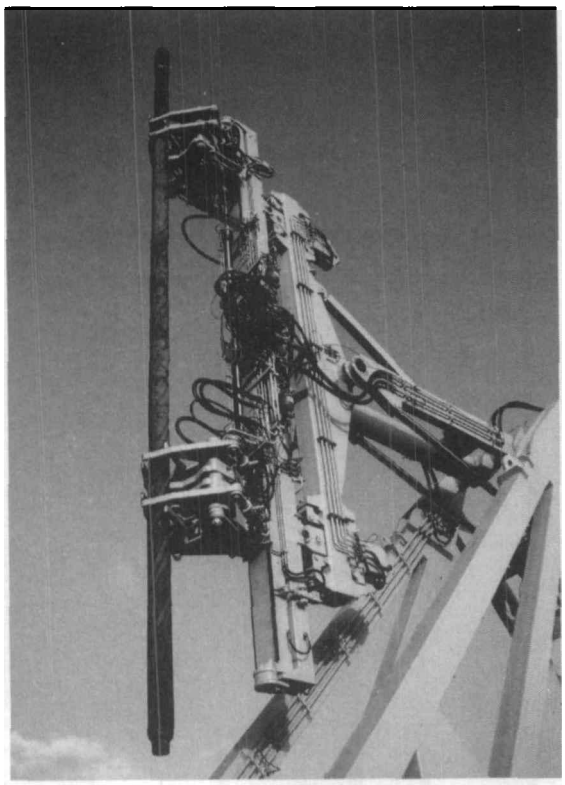


图 2　自动钻杆排放系统增加了工作的安全性并可以减少所需工作人员的数量

4 费　用

开发地热能资源的大部分费用是钻进费用；因此，为了促使地热能开发利用项目在德国的顺利实施，降低钻进费用就成了一项非常重要的先决条件和必要的挑战。由于进行了众多的改进和创新，TI－350 深井钻机在成本节约方面已显示出巨大的潜力。这套复杂的深井钻机设备可以由一个仅仅 4 个人组成的团队来操作。自动钻杆排放系统、维修保养需求低的液压油缸控制起吊系统和不需人工操作的铁钻工可以实现钻杆上扣和脱扣，所有这些都确保了一个小型团队就可以安全顺利地进行运作。该系列的深井钻机可以实现：在不移动整套设备的情况下，钻机的井架能在 10 m 的范围内重新定位。这意味着不需要浪费时间与金钱在组装和拆卸工作上。地热能资源开发的基本特点是施工场地与热能的用户距离很接近，这一点也为进

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一步成本节约提供了机会，另外这套深井钻机不需要花钱采用复杂的噪音防护措施（可以满足要求）。据估计，和传统钻机系统相比，这套深井钻机总共可以节约15%～20%的费用。

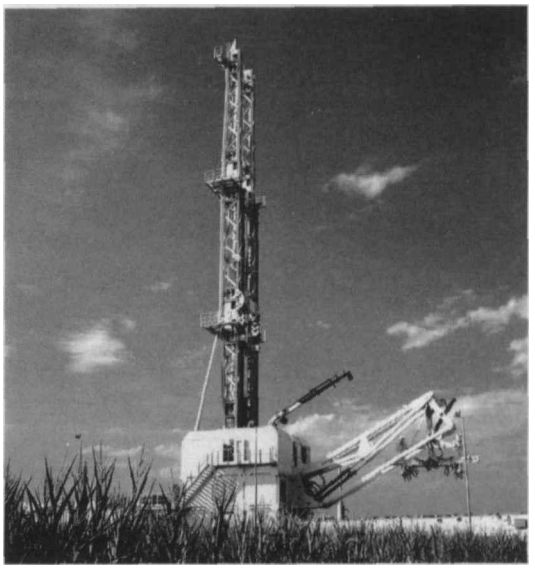


图3 TI-350深井钻机

5 资 金

德国联邦政府已经设立了目标：以后几年里，在整个德意志联邦共和国总能源消费量中大幅度地增加地热能利用的百分比。这意味着，优化、进一步研发及试验一种适应性强及性价比高的深井钻探技术，尤其适用于对深度在2500～5000 m的地热能源的勘探，具有重要的意义。由于需求巨大，地热能源行业早在2006年就提出要实现这项创新的设计理念。该项目与德国联邦政府降低成本、利用可再生能源及保护气候的政策目标具有高度的一致性。所以，TI-350深井钻机的研发得到德国联邦环境、自然保护与核能安全部160万欧元的经费支持而顺利实施（研究项目“为深层地热资源开发研制创新钻机技术”推广编号0327549，项目于2005年8月1日开始进行）。2009年5月，在《可再生能源法案》（EEG）实施后，对利用地热能源发电系统的入网电费进行的改革也将促进对深层地热资源的开发利用。

6 项目经验

早在2006年10月初，该型号的深井钻机在德国Schwanau工厂的一次600深的试验钻孔已证明了该钻机的高效率。第一台TI-350钻机的钻探深度于2008年8月达到了4545 m。这是Hekla Energy GmbH和Exorka International Ltd.合作的地热能源项目的一部分，在慕尼黑西南方向90 km处的Mauerstetten。在钻进的过程中，为了面对出现的新挑战，深井钻机被不断改进完善，包括为了克服施工现场表层地下水磨拉石沉积物所可能造成的问题。这些改进包括：一个液压系统的精巧的附加装置、软件更新、对供应商提供的顶驱进行维修和调整以及配置上的调整，例如调整泥浆泵的脉动阻尼。通过这些改进，使钻机各部分能更高效的协调运作。在Mauerstetten钻探作业期间，灵敏而精密的液压油缸起吊系统被证明十分有利。

第二台TI-350深井钻机于2007年5月交付给客户——位于波茨坦的德国地热研究中心（GFZ）。这台专用于研究的钻机被命名为“InnovaRig”（“创新型钻机”的意思），它根据深层地热科学钻探活动对钻机的特别要求进行了优化。该钻机的顶部驱动由海瑞克子公司Herrenknecht Vertical制造，可以通过中空的大直径（3 ½″）钻杆进行绳索取心钻探。除了科研目的以外，该项目设备还可以用于工业中的商业性项目，以最大限度地发挥其作用。InnovaRig自2007年11月起就被用于德国的多恩哈尔（Dürrnhaar）的一个地热能源项目。第一个钻井于2008年3月成功完成，最终钻进深度为4390 m。随后通过在

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钻孔内投放的测量仪器表明，第一个钻井精确无误。另外一个钻井于2008年12月完成，钻井深度4530 m。自2009年中以来，InnovaRig钻机开始在汉诺威为地热研究中心作业，用于“GeneSys”的地热能源项目中，钻进深度约4200 m的井。如该钻探完成，可为客户BGR（德国联邦地球科学与自然资源研究所）其在汉诺威的整个地质中心（1000名员工）从2012年起提供地热能。尽管工地靠近城区，但Terra Invader钻机配备的精密的噪声防护装置已使周围的居民摆脱了受噪音干扰的担忧。此外，国际大陆科学钻探计划（International Continental Scientific Drilling Program，ICDP）也有意今后采用InnovaRig产品。

另外一台深井钻机于2008年6月用于德国巴伐利亚州Kirchstockach市政的一个地热能源开发项目。Herrenknecht Vertical的工程师们根据之前两台钻机取得的经验对第三台TI－350钻机进行了多项改进。在靠近市区的工地，该深井钻机安全地完成两个钻井中的第一个，设备的有效率高达97%，仅用时101天钻进深度就达到4214m。在最后一段的钻进过程中，设备的有效率甚至达到100%。第二个钻井计划于2009年7月开始钻进。

2009年，另外两台Herrenknecht Vertical Terra Invader 350T用于巴西石油公司Petrobras（世界第三大矿物油公司）的项目。这两台深井钻机将用于一个大型油田的勘探工作。这两台弹弓式深井钻机确保设备可以在偏远地区作业时大量节约时间和成本。由于预先组装好的钻机井架以及井架底座可以以液压方式升起，TI－350T钻机在现场组装和运转时不需要重型起重设备。第一台钻机在2009年6月中旬在Araçás（巴西巴伊亚）投入使用，第二台钻机目前正在运往巴西的途中。

Herrenknecht Vertical GmbH已经成功地凭借产品Terra Invader 350打入地热能源市场。总的来说，钻探设备和它的整套钻探理念及功能已经得到用户的肯定与称赞。液压油缸起吊系统引起了特殊的关注，系统被证明了在针对涉及震动的作业中已经达到了重大的改善，因为它已被配置成可以实现良好的减震。至今为止，只有很少在使用新技术和调试新系统时可能出现的问题在实际操作过程中产生。然而，这些问题都可以通过对工艺技术的改进而得到解决。在设备最初运作的几个月中，深井钻机的学习曲线就已经显著攀升。例如，钻机在多恩哈尔（Dürrnhaar）的使用过程中，其有效率增长迅速（见图4）。各种技

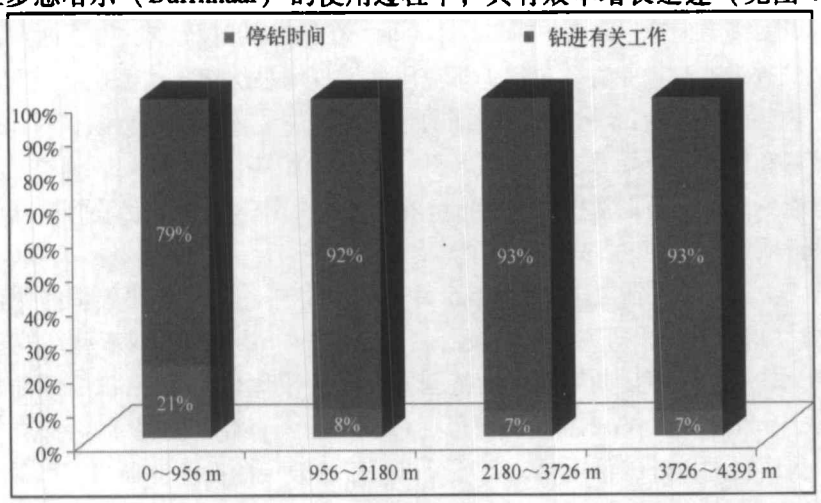


图4　多恩哈尔（Dürrnhaar）深井钻机的有效率

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术上的创新，例如钻杆排放系统、铁钻工，都在实践中显示出它们的价值。深井钻机 Terra Invader 350 在其第一次实际应用就已经明显的表现出超越传统设备的优势。

7 总 结

拥有理想的设备尺寸和设计概念，而且能适应各种地热能源开采项目的深井钻机 Terra Invader 350 达到了预期的期望值；产品还将在其运用过程中不断改善和优化以克服在实践中显露的薄弱环节。该产品及其项目经验为地热能源深井钻探和开发利用的发展和改善探明了新方向。

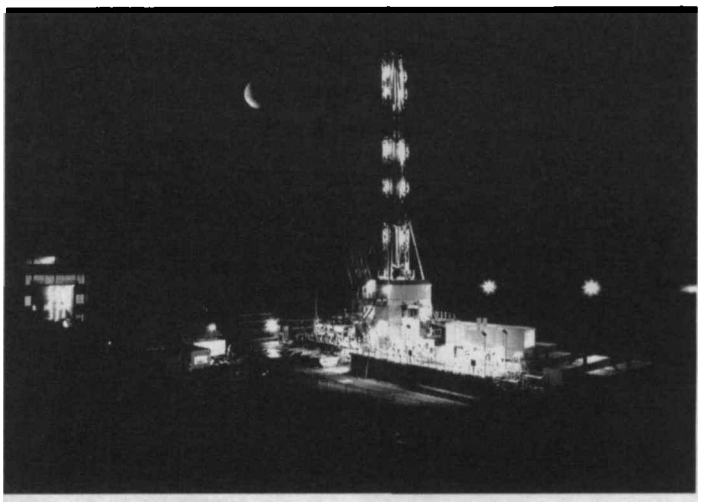


图 5 全新 TI－350 设备的研制有助于改善德国地热能源设备市场缺乏适当产品的现状

此论文中提及的项目由德国联邦环境、自然保护与核能安全部资助，其推广编号为 0327549。

Technology Going Deep: Newly Developed Deep Drilling Rig, Herrenknecht Vertical Terra Invader 350 (TI－350)

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Technically challenging, deep wells down to a depth of 2, 500 to 5, 000 meters are necessary for the efficient exploitation of geothermal energy in Germany. So far, conventional drilling rigs from the oil and natural gas industry have been employed for the exploration of these deep geothermal reservoirs. However, such rigs are not sufficiently adapted to the special requirements of

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deep drills for geothermal energy. Drilling equipment with a hook load of between 250 and 450 tonnes is particularly suitable for exploring the relevant deep drilling areas. However, systems of this size have scarcely been available on the German and European market so far. In response to the demand from the geothermal energy industry, Herrenknecht Vertical GmbH, a subsidiary of Herrenknecht AG, was established in the year 2005 and has now developed the **Terra Invader 350**, a semiautomatic drilling rig with a hook load of 350 tonnes, which outmatches both the conventional requirements of an onshore drilling rig and the special requirements of geothermal energy projects. The current discussion on climate change and the need to develop renewable energy sources prompted the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) to promote this project as part of the energy research program of the German Federal Government.

The development of the TI－350 is based upon the existing drilling technology of oil, gas and well construction rigs, and the experience and knowledge of requirements gained in former geothermal energy projects. Herrenknecht Vertical GmbH has achieved particular improvements in the further development and advancement of deep drilling technology in the areas of automation, energy saving, flexibility when setting up the drilling site and energy supply to the rig, reduction of sound emissions and integration of all systems into a rig. The following issues are of particular relevance for geothermal energy sites.

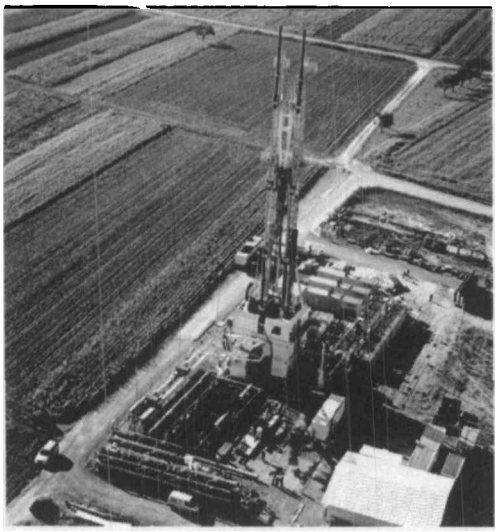


Image 1 The drilling site of the TI－350 requires an area of only 30 m×80 m

1 Drilling site

Geothermal energy must be generated in the vicinity of consumers, i. e. it must be possible to operate the rig in densely built-up areas. The derrick of the TI－350 requires only very little space with an area of 9 m × 10 m. The parts of the rig can be positioned flexibly around the drilling tower, so that the entire drilling rig requires an area of only 30 m × 80 m; furthermore, the remaining space can be used optimally. The size of the drilling site is large enough to carry out the assembly and dismantling of the almost 52-meter-high TI－350, which weighs 370 tonnes.

2 Noise protection measures

In comparison to oil wells, geothermal energy drillings must be carried out close to consumers, in order to guarantee the efficient use of the heat. Therefore, special emphasis was placed on a comprehensive noise protection concept when developing the TI－350. The integrated noise protection system makes it possible to operate the drilling rig even in the direct vicinity of commercial and residential areas. The maximum permissible values for noise emission are not only adhered to, but the emissions lie even below these values. The noise protection measures include enclosed

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mud pumps, generators with optimized exhaust noise suppression and exhaust routing, as well as hydraulic cylinder lifting equipment with pulsation damping. The implementation of these measures has led to a decrease in the noise pressure level at a distance of 150 meters from the drilling site, making it no louder than a low volume TV or radio. Both the staff operating the drilling rig and the residents in the closer vicinity benefit from these noise protection measures.

3 Energy efficiency

A comprehensive energy management concept was implemented for the TI－350 to improve the overall energy balance in a geothermal energy project. The deep drilling rig can be operated alternatively using electricity from the public grid or generators available on the market, which has led to a decrease in emissions in the closer vicinity. Energy is only provided if and when it is actually needed. The majority of the energy - approximately 80% -is used to operate the mud pumps for the conveyance of the cuttings. The pump pressure necessary for a given flowrate depends on the inner diameter of the drill pipes. The larger the diameter, the lower the pressure loss, and therefore the less energy needed. The TI－350 can also be operated with particularly large drill pipe diameters up to $6\frac{5}{8}''$ in order to save energy and costs.

4 Costs

Drilling costs are the major cost factor in the development of geothermal energy reservoirs; therefore, decreasing these costs is an important prerequisite and an essential challenge, to promote the successful implementation of geothermal energy projects in Germany. With the development of the TI－350, supported by its numerous improvements and innovations, an enormous potential for cost saving has been created. The complex drilling rig can be operated by a team of only four. The automatic pipe handling system, the reduced-maintenance cylinder hoisting system and the hands-off technology of the iron roughneck for make-up and break-out of the drill pipes all ensure that the operation runs smoothly, safely and with a small team. The drilling rig is designed in such a way that the derrick can be relocated by up to ten meters without having to move the entire rig. This means that no costly and time-consuming assembly or dismantling work is necessary. Further cost-saving opportunities are provided by the proximity to the electricity and heat

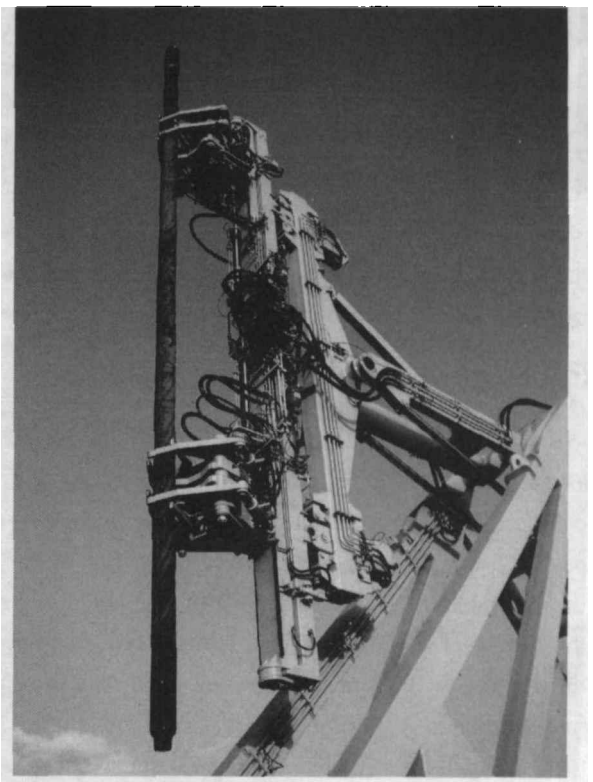


Image 2 The automatic pipe handling system increases safety at work and reduces the number of staff required

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consumers-an essential feature of successful and cost-efficient geothermal energy projects - and the fact that no costs are necessary for comprehensive noise protection measures. It is assumed that the overall savings potential, compared with conventional systems, amounts to 15% ~20%.

5 Funding

The German Federal Government has set itself the target of increasing considerably the percentage of geothermal energy in the overall energy consumption of the Federal Republic of Germany in the next few years. In this context, the optimization, further development and testing of an adapted and cost-efficient deep drilling technology, particularly for the exploration of geothermal energy resources at depths of 2, 500 to 5, 000 meters, will play a decisive role. Because of the high demand, the geothermal energy market prompted the realization of an innovative design concept for this task as early as the year 2006. The project is in line with the grant policy objectives of the German Federal Government concerning a cost-saving and environmentally friendly extension of renewable energies and climate protection. Therefore, the development of the Terra Invader 350 drilling rig was funded by the BMU to the tune of approximately 1.6 million euro (research project "Development of a new drilling rig technology for deep geothermal energy", promotional reference 0327549, project start: 1 August 2005). The planned improvement of the feed-in tariff for electricity generated by geothermal energy systems after the Renewable Energy Sources Act (EEG) comes into force in 2009 may also promote the increased exploitation of deep geothermal energy.

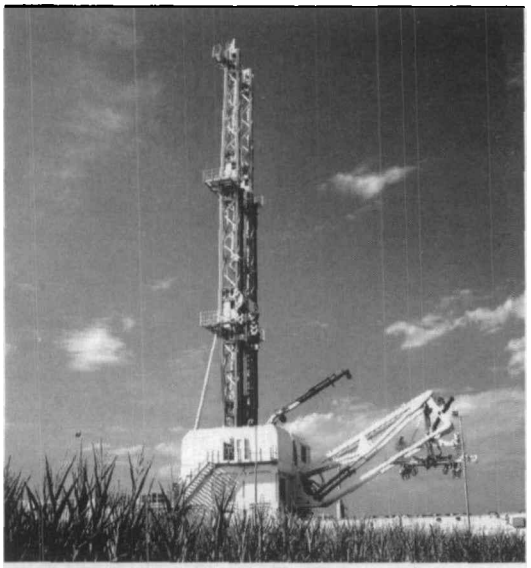


Image 3 The first deep drilling rig of the TI-350 type

6 Experience in the field

The rig proved its efficiency at the Herrenknecht Vertical GmbH plant site in Schwanau with a test borehole at a depth of 600 m as early as the beginning of October 2006. The first TI-350 deep drilling rig successfully drilled one well down to a depth of 4, 545m in August 2008. It is part of the joint geothermal energy project of Hekla Energy GmbH and Exorka International Ltd. in Mauerstetten, 90km southwest of Munich. Changes to the deep drilling rig have been made in the course of the drilling activities in order to overcome the challenges encountered, including those posed by the upper freshwater molasse sediments at the site. The improvements include a refinement of the hydraulic system, software updates, a Herrenknecht internal repair of a contractor's Top Drive as well as constructional changes, e.g. at the pulsation damping of the mud pumps. Through these developments, the interaction of all rig components could be improved significantly. During fishing works in Mauerstetten, the sensitive and accurate hydraulic cylinder

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hoisting equipment proved to be very advantageous.

A second drilling rig of the type TI－350 was delivered to its customer, the German Research Centre for Geosciences (GFZ) Potsdam, in May 2007. The research drilling rig, named InnovaRig, was optimized in particular with a view to the requirements of scientific deep drilling activities. It is operated with a Top Drive made by Herrenknecht Vertical, which allows for wireline coring through the large inner diameter (3 ½″) of the hollow shaft. In addition to scientific applications, the system is also made available for commercial projects in industry to achieve a maximum utilization capacity. The InnovaRig has been employed for a geothermal energy project in Dürrnhaar since November 2007. The first of two wells was successfully completed with a final depth of 4390 m in March 2008. The subsequent transport of the measuring equipment through the borehole confirmed the immaculate condition of this first drilling. The second well was completed with a final depth of 4530 m in December 2008. Since mid 2009, the InnovaRig has been working for the GFZ in Hanover. It is deployed to drill one well of approx. 4200 m in depth for the "GeneSys" geothermal energy project. This will allow the customer BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) to heat the entire GEOZENTRUM Hanover (1000 employees) from 2012 on. Close to urban areas, the Terra Invader has already convinced the residents due to its sophisticated noise protection. Furthermore, use of the InnovaRig is planned as part of the International Continental Scientific Drilling Program (ICDP) in the future.

Another deep drilling rig was delivered for a project for geothermal energy production in the Bavarian municipality of Kirchstockach in June 2008. Herrenknecht Vertical engineers benefited from the project experience gained with the first two rigs, which helped improve several design features of the third TI－350. Close to urban areas, the rig safely drilled the first of two wells with an availability of 97% in only 101 days, down to a final depth of 4214 m. The last section of the well was even drilled with a maximum machine availability rate of 100%. Start time for drilling of the second well is planned for July 2009.

Also in 2009, two Herrenknecht Vertical Terra Invader 350T rigs will go to work for the Brazilian oil and gas company Petrobras, which is the third largest mineral oil company in the world. They will be used for exploratory drills in a large oilfield. The two slingshot type rigs are equipped with a technical innovation which offers considerable time and cost savings in remote locations. Since the pre-assembled substructure and the drilling mast can be erected hydraulically, no heavy duty cranes are necessary to assemble the TI－350T in the field and put it into operation. The first rig started operation in Araçás (Bahia) in mid June 2009, the second is currently being transported to Brazil.

Herrenknecht Vertical GmbH has managed to enter the geothermal energy market successfully with the Terra Invader 350. In general, the drilling rig and its overall concept as well as its functionality have been praised by users. The hydraulic cylinder hoisting system attracted special attention in this respect. It proved to be an important improvement especially for jobs involving jars, as it is well suited for shock absorption and damping. Only a few initial problems have so far arisen during practical implementation, which is usual when introducing new technologies and commissioning new systems. These difficulties can and will, however, be solved by means of targeted improvements to the process technology. During its first months in operation, the rig already spanned a steep learning curve: considering, for example, the availability of the rig during its use

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in Dürrnhaar, it is clear that its availability increased significantly in the course of the drilling work (image 4) . The technological innovations, such as the pipe handling system and the iron roughneck, have demonstrated their value during operation. The Terra Invader 350 has clearly shown its numerous advantages over conventional rigs even in its first applications.

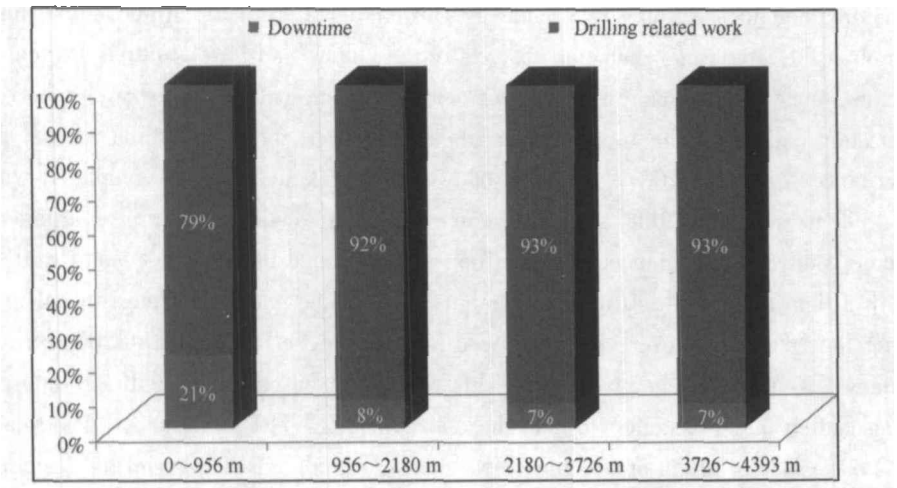


Image 4 Availability during the geothermal energy drilling at Dürrnhaar

7 Summary

The Terra Invader 350, which has the ideal size and design concept for implementation in geothermal energy projects, has largely met the expectations placed on it; the rig will be continuously optimized to remove the weak points recognized during its use. The drilling has shown new directions for the targeted development and improvement of deep drilling technology for use in geothermal energy projects.

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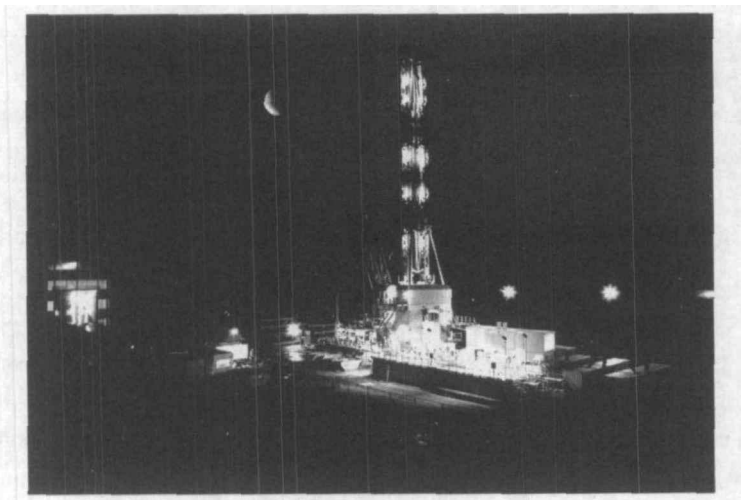


Image 5 The manufacture of further TI－350 units will help to remedy the shortage of appropriate drilling rigs on the German geothermal energy market

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