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Permanent Magnet Machines For Elevators In Super High-Rise Buildings

超高层建筑电梯所采用的永磁曳引机

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Zbigniew Jerry Piech received the M.S. and Ph.D. degrees in electrical engineering from Technical University of Wroclaw, Poland in 1975 and 1982, respectively. He joined UTC Research Center in 1990 as a senior research engineer assigned to advanced propulsion programs. Jerry left UTC to serve as R&D director at Anorad Corporation. He returned to UTC and joined Otis in 1998. He had a leading role in establishing permanent magnet motor technology as the standard for Otis Elevator hoist machines. Dr. Piech is an Otis Fellow (United Technologies Corporation, USA) and member of Connecticut Academy of Science and Engineering (CASE).

杰里•皮耶希于1975年在波兰弗罗茨瓦夫理工大学获得硕士学位，并于1982年获得博士学位。1990年加入联合技术研究中心 (UTC Research Center)，成为一名高级研究工程师，负责先进推进系统项目。杰里曾一度离开联合技术，担任Anorad公司的研发总监。而后又回到联合技术 (UTC) 工作，并于1998年加入奥的斯，是永磁电机技术开发的领导者之一，并使该技术成为奥的斯电梯曳引机的技术标准，皮耶希博士还是康涅狄格州科学与工程学院 (CASE) 院士，也是联合技术公司奥的斯电梯的高级专家。

Abstract

This paper introduces the new approach to design and construction of permanent magnet elevator machines targeting super high-rise buildings. The increased demand for high-rise buildings poses challenges to designers, manufacturers and maintenance companies tasked with adequately moving people to the higher and higher building floors. The new series of hoist machines described in this paper addresses these challenges. Simplified installations, low foot-print and environmentally friendly set up, are just a few significant advantages distinguishing the proposed elevator propulsion system from the past methodologies. In particular, adopting this innovative machine architecture provides improved motor energy efficiency, decreased machine size and weight, while simultaneously increasing the machine lifting capacity. Furthermore, these new machines are designed to work with multiple modular drives, facilitating configuration flexibility for the whole elevator propulsion system architecture. In brief, these machines address all the needs of the current and future high-rise building demands.

Keywords: Elevators, PMSM Machines, Modular Propulsion, Design for Performance

摘要

本文介绍的是超高层建筑电梯所采用的永磁曳引机的新型设计和建造方法。当人们对高层建筑提出更高要求的同时，也要求设计师、制造厂家和维护企业有能力将人们送到越来越高的楼层。实现这一过程需要解决诸多问题，因此新型曳引机系列应运而生，与以往的技术工艺相比，安装程序简便、占地面积更小、低碳环保是所推荐的电梯推进系统的几个显著特点。特别值得关注的是，采纳此新型机器架构可以大幅提高电机能效，同时使机器更小、更轻，并提高机器的提升能力。另外，这些新型机器旨在配合多模块驱动系统运行，使整个电梯推进系统架构的配置更加灵活。简而言之，该系列的机器可以满足当前和未来高层建筑对电梯的需求。

关键词: 电梯、永磁同步电机、模块化推进、性能设计

Introduction

The increasing demand for elevator systems, suitable for installation in megatall and supertall rise buildings has triggered the recent development of a completely new elevator power train. Consequently, hoist machine structures, motor-drive architecture, state-of-the-art design of motor electromagnetic components, and innovative cooling methods facilitated significant reduction of machine size and weight, while maintaining high efficiency power conversion.

Transporting a heavy hoist machine from the ground level to its target destination within a high-rise building (often for more than 500 meters vertical lifts) constitutes a difficult, logistically complicated and very expensive one time operation. It has required the construction of a devoted platform on top of the building for specialized crane lifting

介绍

为了满足在大型高层建筑和超高层建筑中的安装需求，人们对电梯系统的要求日益提高，促使了新型电梯动力总成的研发。诞生了新型的曳引机结构、电动驱动架构、电机电磁组件的先进设计，以及创新的冷却方法，促进机器变得更小、更轻，同时保持高效的能源转换。

高层建筑内部 (通常是指垂直升降距离超过500米)，将笨重的曳引机从底层向上运输到最终安装点，这一过程本身就非常困难，而且一次性操作的运输安排非常复杂，并且费用也十分高昂。这要求在建筑顶部建设一个专用平台，用于专业起重机的曳引操作 (参见图1)。相应地，如果减少主机重量，则可以消除，或者说至少可以尽量减少主机在曳引操作期间由于专业起重设备的应用产生的复杂性和费用。因此，奥的斯开发团队将最大程度地降低曳引机重量作为首要问题。

Figure 1. SkywayTM machine being lifted to the top of Burj Khalifa building in Dubai, (Source: Otis Elevator Company)
图1. SkywayTM 主机被提吊到迪拜的迪拜塔塔顶 (资料来源: 奥的斯电梯公司)

operation, (see Figure 1). Accordingly, machine weight reduction could eliminate or at least diminish the complexities and costs associated with the application of special crane equipment during the machine lifting operation. Thus, the Otis development team set to minimize the hoist machine weight as the first challenge.

Successful integration of the motor and machine sheave, allowed the new Otis SkyMotion™ series machines to be lighter than their Skyway™ predecessors. In particular, SkyMotion™ 250, 400, and 800 machines weigh 21%, 37% and 48% less than Skyway™ 40T, 70T, 100T machines, respectively. However, despite their lower weight and smaller sizes, the new machines boast significant performance improvements. Additionally, they are designed and constructed as an assembly of a few major structural blocks. This segmentation facilitates separate transportation of each block to the top of the building and then reassembly in the machine room directly over the elevator shaft.

The overall dimensions, weight, maximum duty load, maximum speed and maximum rise of the elevator systems served by SkyMotion™ machines are specified (see Table 1). The machines are constructed as synchronous motors with external rotor having embedded permanent magnets and with concentrated coils wound around laminated steel teeth forming the motor stators all cooled by a single blower. The electro-mechanical properties of the new machine series are as follows:

- SkyMotion™ 800 develops 70 kNm peak torque at acceleration and produces 21.6 kNm of torque during the rated 15 m/s run. The rated power conversion is accomplished with 97.5% efficiency.
- SkyMotion™ 400 develops 38.7 kNm of acceleration torque with 16.9 kNm capable of running a double decker elevator at the rated 15 m/s or a single deck elevator at 20 m/s. The rated power conversion efficiency is 96.5%.
- The smallest SkyMotion™ machines are constructed in two versions: 200 and 250. Just as 400 and 800 models, the SkyMotion™ 200 is designed as single wrap traction. It develops 17.7 kNm acceleration torque, 5.6 kNm of rated torque and maximum speed of 10 m/s. Meanwhile, SkyMotion™ 250 supports higher duty loads and rises, and is built with double wrap traction.

Frequently, the elevator propulsion system power conversion efficiency is the most important parameter for the end user, building owners. By installing high efficiency machine-drive units, building owners benefit directly from energy cost savings. Efficient machines and drives also release less heat, reducing cooling and climate control requirements for the machine room. Furthermore, higher efficiency machines

通过成功地将电机和曳引轮集成在一起，使新一代的奥的斯SkyMotion™系列的重量比其上代Skyway™系列更轻。尤其是，SkyMotion™ 250、400和800的重量分别比Skyway™ 40T、70T、100T的重量低21%、37%和48%。尽管新系列已经拥有更小尺寸和更小重量的优点，此新型机器还宣称其拥有更加卓越的性能。另外，这些机器的设计和结构实现了将整套设备分为几个部分进行组装。这种分段化的结构有助于分批将每个部分运输到建筑物的楼顶，进而直接在电梯井上方的机房内重新组装起来。

SkyMotion™ 机器所服务的电梯系统整体尺寸、重量、最大额定载重、最高速度和最大提升高度等指标已经确定 (参见表1) 。该系列的构造使电机与嵌入永磁的外转子同步运行，并使用集中线圈缠绕层压钢牙构成电机定子，全部组件均通过一台风机进行冷却。新机器系列的电气和机械性能如下:

- SkyMotion™ 800在加速时可产生 70 kNm的峰值扭矩，在以额定速率15米/秒运转期间产生21.6 kNm的扭矩。额定功率转换能效达到97.5%。
- SkyMotion™ 700产生38.7 kNm的加速扭矩，具有16.9kNm的额定扭矩，能够驱动一台双轿厢电梯在以额定速率15米/秒运行，或者能够驱动一台单轿厢电梯运行于20米/秒的速度。额定功率转换效率为96.5%。
- 体积最小的SkyMotion™ 系列有两个版本的结构: 200 和 250 。如同400型和800型，SkyMotion™ 200 按照单绕式曳引进行设计，产生17.7 kNm的加速扭矩，具有5.6 kNm的额定扭矩，最高速度为10米/秒。而SkyMotion™ 250 采用复绕式曳引，支持更高的额定载重和提升高度。

通常情况下，对于最终用户和业主来说，电梯推进系统的能量转换效率是最重要的参数。通过安装高效机器驱动装置，使业主可以直接从节约能耗中受益。高效的机器和驱动系统会释放更少的热量，从而减少对机房冷却和环境气温控制的要求。另外，由于驱动系统的尺寸大小是由加速期间和正常终端减速 (NTSD) 期间的峰值输入功率界定的，因此越是高效能的机器，需要的驱动部件的尺寸也就越小，所以，高效能的机器也使采用奥的斯电梯的承包商受益。

对于 SkyMotion™ 而言，虽然与以往的机器系列相比，其额定载重和提升高度已经有了显著提升，但仍然可以利用现有较小的驱动系统，而无需使用更大的装置。使用模块化、高效PMSM电机绕阻并且允许使用支持一台单速曳引机的多驱动系统可实现上述设计用途。

MACHINE	 SkyMotion 250	 SkyMotion 400	 SkyMotion800
Duty & Speed DD- Double Deck Car	3000 kg @ 10 m/s 1:1 roping	2000 kg @ 20 m/s SD 5000 kg @ 15 m/s DD 1:1 roping	5000 kg @ 15 m/s DD 1:1 roping
Rise (maximum)	250 m 300 m	600 m @ 2000 kg 300 m @ 5000 kg	600 m
Sheave Diameter	900 mm	1100 mm	1250mm
SSL Actual SWT *DWT Equivalent*	25,000 kg *50,000 kg*	41,000 kg *82,000 kg*	78,000 kg *156,000 kg*
Weight	5350 kg w. bedplate w/o deflector sheave	9940 kg w. bedplate w/o deflector sheave	12500 kg w. bedplate w/o deflector sheave
Dimensions CL- end x W x H (incl. bedplate) mm	800 x 1419 x 1550	903 x 1730 x 1914	1108 x 1780 x 2043

Table 1. Specification of basic parameters of SkyMotionTM machines, (Source: Otis Elevator Company)
表1. SkyMotionTM 主机的基本参数列表 (资料来源: 奥的斯电梯公司)

benefit the Otis elevator contractor, requiring smaller drives, as their sizes are defined by peak input power during acceleration and during Normal Terminal Slowdown (NTSD).

In case of the SkyMotion™ machines, it was possible to utilize existing smaller drives rather than building larger units, despite significant extension of the Duty Load and Rise coverage compared to the previous series of machines. This was achieved using modular, high efficiency PMSM motor windings and allowed utilization of multiple drive system to support a single hoist machine.

One of the SkyMotion™ machine's unique features is its stator cooling system. The novel design was necessitated by the location of the stator inside of the integrated machine sheave housing the permanent magnet rotor. Due to high concentrations of the motor windings heat sources within confined space of the rotating sheave/rotor drum assembly, recirculating closed loop liquid coolant system appeared to be the most appealing solution. However, this would require adding weight to the machine, while reducing reliability associated with mechanical pumps and valves. In the end, the design team decided to focus on forced air cooling. Its implementation consisted of a hollow tube stationary shaft supporting the motor stator structure designed to deliver cooling air into the integrated sheave-PM rotor internal space.

The cold air, compressed by a variable speed blower, is forced through the stationary shaft-pipe and distributed by a series of shaft openings into the stator structure. The cool air flowing in both axial directions along the stator's back iron internal cylinder absorbed the heat from the surrounding windings. This elevated temperature air is then forced outside the machine structure through openings machined into both sides of the rotating sheave/rotor drum assembly. Such air distribution cooling circuit, combined with an on-demand adjustable speed blower and encapsulated winding insulation system characterized by high thermal conductivity, ensured operational temperature below 135 degrees Celsius.

Impact on Machine Room Arrangement and Size

The regional code requirements (i.e. EN and ANSI) imply that all hoist machine frames should fit the smallest defined hoist way projection. This constrained design for the new hoist motor series required the SkyMotion™ machines to have much smaller sizes, compared to the predecessor Skyway™ series. It is illustrated how traditional oversized machines must be arranged in the machine room serving multiple hoist ways in order to fit above their projections and not interfere with machine room walls and with each other (see Figure 2). Consequently, the conventional machine room is oversized with envelope dimensions exceeding typical height between building floors.

Decreasing the machine size, placing special emphasis on reducing the base footprint was a difficult challenge to the design teams. This step was necessary to fit the new machines directly into projection of the elevator shaft. An additional requirement was to enable installation of multiple units on the same level (floor) in the machine room serving multiple shafts in order to avoid partial stagger of group hoist machines vertically.

The final design regarding machine compactness and their symmetry around the geometrical center line of the sheave (CL) exceeded expectations, allowing for suitable installation directly over the elevator shafts, with adequate separation of multiple units and the enclosing

SkyMotion™机器的一个独有特征是定子冷却系统。由于定子位于包含永磁转子的一体式曳引轮罩中，这需要采用新型设计。由于电机绕阻热源高度集中在旋转轮/转鼓总成的有限空间中，因此，循环闭合环路液体冷却系统显然是最有吸引力的解决方案。但这样一来，势必会增加机器重量，同时因需采用泵和阀门而降低了可靠性。最终，设计团队决定将重点放在强制风冷系统的设计上。该风冷系统由一个支持定子结构的空心管固定轴构成，将冷却空气送入一体式槽轮——永磁转子的内部空间。

变速风机压缩后的冷空气被强制输送到固定轴管中，再由一系列的轴孔分布到定子结构中。冷空气沿着定子护铁内筒向两个轴向流动，吸收周围绕组的热量。之后，温度升高的空气被强制从转轮/转鼓总成两侧的机械开孔排放到机器结构外部。这类空气分配冷却环路与一台按需调速风机和封装绕组绝缘系统结合使用，其特点是具有高导热系数，确保将工作温度控制在135摄氏度以下。

对机房布置和机房大小的影响

地区性标准 (如: EN和ANSI) 要求所有曳引机机架与界定的最小电梯井投影面积配合。这使新型曳引电机系列的设计需要使SkyMotion™机器尺寸远远小于之前的Skyway™系列。为了获得上述投影面积，并且与机房围壁不产生干扰，而且彼此之间也互不妨碍，图中说明了在机房内必须布置的传统超大尺寸机器是如何为多电梯井提供服务的 (参见图2) 。结果，传统机房具有超大的体积，轮廓尺寸也超出了楼层之间的常规高度

缩减机器尺寸，特别是减少机座占地面积是设计团队需要克服的难题。这是将新型机器直接安装到电梯井的投影区域中的必要步骤。另一个要求是通过在服务于多电梯井的机房中的同一水平 (楼层) 上安装多台装置，从而避免成组的曳引机在垂直方向局部错位安装。

有关机器紧凑性以及围绕槽轮的几何中心线 (CL) 对称性的最终设计超过了预期效果，可以恰当地将装置直接安装在电梯井上方，并且使多台式装置之间与机房围壁之间有充足间隙。将SkyMotion™ 机器俯视图与之前的Skyway™系列机器厢体的俯视图进行对比 (参见图3和图4) ，可以很清楚地看出设计成果。从这些图纸上可以清楚地看到，新型机器与建筑墙面和邻近的设备互不干扰。

与之前的Skyway系列比较，新款SkyMotion™ 机器的投影面积和体积的具体减少比例如下: 与Skyway™ 40T相比，SkyMotion™ 250的面

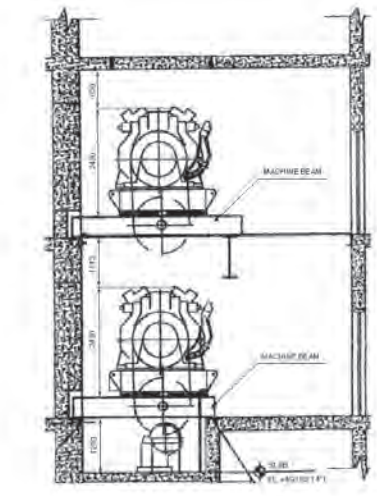

Figure 2. Vertical arrangement of oversized machines in the machine room, (Source: Otis Elevator Company)
图2. 超大尺寸主机在机房中的纵向布置 (资料来源: 奥的斯电梯公司)

machine room walls. The results are illustrated with the top views of the SkyMotion™ machines compared to the predecessor machine Skyway™ series envelopes (see Figure 3 and Figure 4). It is clear from these drawings that the new machines do not interfere with building walls and nearby equipment.

The specific area and volume savings of the new SkyMotion™ machines, compared with their Skyway predecessors, are as follows: 30% in area and 41% in cubic volume for the SkyMotion™ 250 over the Skyway™ 40T; 24% in area and 29% in cubic volumes for the SkyMotion™ 400 over Skyway™ 70T; and 27% in area and 33% in cubic volume for the SkyMotion™ 800 over the Skyway™ 100T machine. Such size reductions benefit building owners directly reducing the machine room foot-print and volume, offering architects more space for other building functions. Smaller machines also benefit the service crew and afford simplified maintenance with more space available around each hoist machine.

Machine Mechanical Structure

The machine and its bedplate are designed with symmetry plane perpendicular to the sheave axis. This arrangement offers position flexibility, while installing the machine over hoistway shafts and avoids physical interferences with machines over the neighboring shafts. Two side stands positioned on the bedplate constitute the main structural components supporting the whole machine. These stands are integrated with stationary hollow shaft securing the bearing cartridges and electric motor stator. The shaft provides a channel for cooling air injected by a blower installed on one of the side stands. It also functions as a conduit for electric cables connecting motor winding with terminal box mounted on the second side stand.

The two machine bearings are identical and enclosed in special cartridges filled with lubricating oil. The use of oil rather than grease, along with placement of observation windows within the cartridge walls, allows for precise assessment of the lubricant condition. In particular, oil level and contamination are clearly visible by looking through the side stand windows. Similarly, lubricant refiling or replacement service takes only a fraction (approximately 1 hour) of the time required for traditional grease application service (approx. one day).

The machines are equipped with caliper brakes that engage brake disk(s) (end bells). In case of the SkyMotion™ 400 machine, its sheave is terminated with two brake disks, engineered into both side stands. This machine contains up to four locations (two on each stand) for placement of the calipers brakes. In contrast, the SkyMotion™ 250 and 800 series machines integrate a single brake disk. Accordingly, the stand located near that disk can accommodates only two caliper brakes. The specific brake configurations are chosen based on by duty load coverage, type of caliper brakes and brake redundancy requirements. The Duty Load and braking torque requirements of SkyMotion™ 250 machine are satisfied by utilizing two electromagnetically activated calipers. The SkyMotion™ 400 machine requires two different configurations for the braking system. The lower duty machine (Duty Load up to 2500 kg) is equipped with two electromagnetic caliper brakes. Meanwhile, higher duty machine (Duty Load over 2500 kg) integrates four electromagnetic caliper brakes. Due to significantly greater braking torque requirements, the SkyMotion™ 800 machine cannot be deployed even with four electromagnetic caliper brakes. Consequently, two hydraulic calipers are used instead.

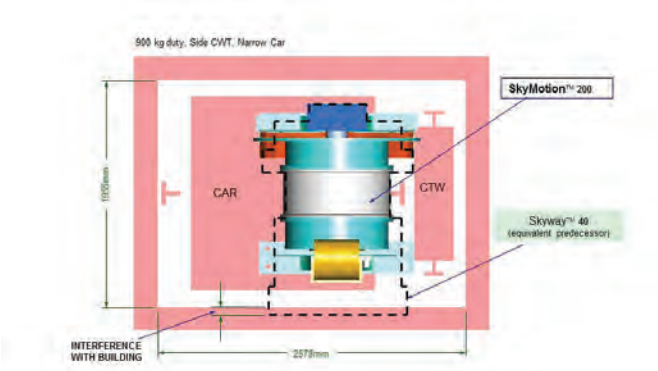

Figure 3. Footprint comparison for SkyMotionTM 200 and SkywayTM 40 machines, (Source: Otis Elevator Company)
图3. SkyMotionTM 200 和 SkywayTM 40主机的占地面积对比 (资料来源: 奥的斯电梯公司)

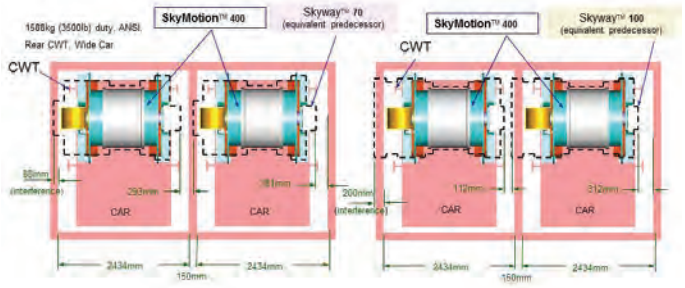

Figure 4. Footprint comparison for SkyMotionTM 400 machine versus SkywayTM 70 (left drawing) and SkywayTM 100 (right drawing). (Source: Otis Elevator Company)
图4. SkyMotionTM 400 与 SkywayTM 70 (左图) 和SkywayTM 100 (右图) 的占地面积对比 (资料来源: 奥的斯电梯公司)

积减少了30%，体积减少了41%; 与Skyway™ 70T相比，SkyMotion™ 400的面积减少了24%，体积减少了29%; 与Skyway™ 100T相比，SkyMotion™ 800的面积减少了27%，体积减少了33%。此种尺寸缩减减少了机房的占地面积和体积，使建筑师有更多的空间实现其他楼宇功能，从而使业主直接受益。缩小机器尺寸后，由于每台曳引机周围有了更大的空间，因此也使得维护保养工作更加便利、简单。

机器的机械结构

机器和底座板的设计使对称平面垂直于曳引轮轴线。这种布置使得在电梯井上方的机器安装工作能够灵活地定位，避免机器与邻近的井壁发生物理干扰。两侧的支架布置在座板上，构成支撑整个机器的主要结构件。这些支架与固定式空心轴组装在一起，用于固定轴承盒与电机定子。空心轴为一侧支架上的风机注入的冷却空气提供了输送管道。还能够作为电缆管道使用，使电机绕组一端的电缆从中穿过连接到另一侧支架上的端接盒。

两只完全一样的电机轴承封装在一个专用轴承箱内，注满润滑油。我们采用油而不是油脂，并且在轴承箱壁内布置观察孔，从而能够准确地评估润滑剂的状况。尤其是，通过侧面支架窗口可以清晰地观察到油位和污染程度。同理，这也大大缩短了加注润滑剂或者更换润滑剂的时间，此新型设计只需1小时左右，而传统润滑工作几乎需要1天的时间。

此款机器配置了与制动盘 (端铃) 耦合的夹式刹车器。对于SkyMotion™ 400机器，其曳引轮与两个制动盘连接，嵌入两侧的支架。此款电机可以在四个位置 (每支架两个) 布置夹式刹车器。相比之下，SkyMotion™ 250 和800系列机器只包含一个制动盘。相应地，位于该制动盘旁边的支架只能容纳两个夹式刹车器。

Figure 5. Side view of SkyMotionTM 400 machine, (Source: Otis Elevator Company)
图5. SkyMotionTM 400的侧视图 (资料来源: 奥的斯电梯公司)

Finally, the main sheave comprises one of most advanced and innovative components of the SkyMotion™ series machine. It integrates external rotor of the brushless PM synchronous motor with the machine sheave and fulfills a dual function. Primarily, the sheave guarantees adequate traction between grooves and ropes thanks to a unique treatment with Stellite alloy on its external surfaces. Secondly, it hosts permanent magnets which partially conduct the excitation magnetic field. In addition, the sheave structure dissipates portion of the heat generated within the machine through the sheave surface. The integration of a sheave with permanent magnet (PM) rotor afforded significant weight and size reduction of the entire machine. The machine picture (SkyMotion™ 400) is presented (see Figure 5).

Electrical System of SkyMotion™ Power Train

The electrical provisions for each propulsion system differ from each other and are defined by peak power demand during acceleration of a fully loaded elevator car. The selected electrical performance parameters of the drive-motor power train are specified for each SkyMotion™ machine (see Table 2).

The machines are powered by existing Otis drives. One of the requirements during the development of new SkyMotion™ high-rise propulsion system was to implement the segmentation and grouping of each stator winding into discrete sets. This was motivated by a desire to match with the existing Skyway™ drives. Each group of stator windings can be supplied by one individual drive. Alternatively, some winding groups can be connected in parallel to form a single drive. This arrangement flexibility for existing drives and new machines creates convenient modular coordination to cover various elevator needs.

依据额定载重量、夹式刹车器的类型和制动冗余要求选择具体的制动器配置。利用两个电磁启动制动钳可以满足SkyMotion™ 250机器的额定载重量和制动扭矩要求。SkyMotion™ 400机器要求制动系统有两套不同的配置。低负载机器 (额定载重量为2500千克) 配备两部电磁夹式刹车器。高负载机器 (额定载重量超过2500千克) 组装四部电磁夹式刹车器，由于制动扭矩要求大幅提高，SkyMotion™ 800机器即使安装四部电磁夹式刹车器也无法使用。取而代之的是，选择使用两台液压制动钳。

最后，主曳引轮由最先进的新型SkyMotion™系列机器组件构成。将无刷永磁同步电机的外转子与曳引轮集成在一起，实现双重功能。首先，通过在曳引轮外表面上使用钨铬钴合金进行一种特殊处理，保证槽与绳之间有充足的牵引力。其次，它包含部分产生励磁磁场的永磁体。另外，槽轮结构可以通过槽轮表面消散机器内部产生的部分热量。槽轮与永磁 (PM) 转子的集成促使整台机器的重量和尺寸均大幅缩减。本文中展示了该机器 (SkyMotion™ 400) 的图片 (参见图5)。

SkyMotion™ 动力总成的电子系统

每套推进系统的电气设备各有不同，由满负荷电梯轿厢在加速期间的峰值功率需求决定。选定的驱动电机动力总成电气性能参数特别适用于每台SkyMotion™机器 (参见表2)。

此款机器由现有奥的斯驱动系统提供动力。在新型高层推进系统研发期间的一个要求是实现分段化，并且使每个定子绕组集中在分立组件中。实现此设计之后就可以与现有驱动系统匹配。每组的定子绕组都可以由一个单独的驱动系统供应。或者，部分绕组组合可以并联形成一个单独的驱动系统。现有驱动类型和新型机器的布置灵活性可方便进行模块化协调，从而满足各类电梯要求。

为每台机器提供动力的驱动系统数量和尺寸取决于电梯系统额定载重量DL和额定速度。例如，当在一部SkyMotion™ 400机器在额定载重量DL = 2500千克、额定速度 = 15米/秒的电梯中使用时，则使用一台功率最大的奥的斯驱动系统。反之，如果额定载重量DL超过2500千克，但额定速度相同，此驱动系统则需要使用两部。

当电梯额定速度不超过10米/秒，并且具有经济可行性时，通常使用两台功率较小的驱动系统。对于多动力机器，本文给出了几个电气连接示例 (参见图6)。

POWER TRAIN 动力传动系	*SkyMotion 250*	*SkyMotion 400*	*SkyMotion 800*
Number of Available Motor Winding Systems 可用电机绕组数	2	2	4
Number of Phases 阶段数	3	3	6
Rated Current 额定电流	2 x (125 A_{ms} Per Drive)	2 x (195 A_{ms} Per Drive) 2 x (285 A_{ms} Per Drive)	4 x (152 A_{ms} Per Drive)
Maximum Acceleration Current 最大加速电流	2 x (1336 A_{ms} Per Drive)	2 x (695 A_{ms} Per Drive) 2 x (670 A_{ms} Per Drive)	4 x (485 A_{ms} Per Drive)
Rated Motor Input Power 额定电动机输入功率	190 kW	320 kW 475 kW	535 kW
Maximum Acceleration Motor Input Power 加速期间电动机最大输入功率	385 kW	885 kW 840 kW	1335 kW
Rated PF 额定PF	0.940	0.945	0.980

Table 2. Electrical characteristic of SkyMotionTM power train series, (Source: Otis Elevator Company)
表2. SkyMotionTM 动力总成系列的电气特性 (资料来源: 奥的斯电梯公司)

The number and size of drives powering each machine depends on the elevator system duty load DL and required speed. For example, when a SkyMotion™ 400 machine is used in an elevator with DL = 2500 kg and speed = 15 m/s, then a single, most powerful Otis drive is employed. In contrast, if duty load, DL is higher than 2500 kg, with the same speed specification, then two such drives are needed.

Typically, for rated elevator speeds not exceeding 10 m/s and when it is economically justified, two smaller drives are used. A few examples of electrical connections, for multi-drive machines, are illustrated (see Figure 6).

Conclusion

The new SkyMotion™ system presents significant extension of super high-rise elevator capability presently not available in the industry. The introduced power train enables construction of elevators with double or triple deck cars running with speeds of 15 m/s and with rises up to 600 meters. Furthermore, the SkyMotion™ 400 system permits construction of elevators with rated speed of up to 20 m/s.

The smaller size of SkyMotion™ power train translates into smaller machine room and simpler installation of the lifting equipment, which in turn, offers more design freedom to high-rise building architects. The reduced weight of the machine decreases the size and cost of hardware, logistic expenses and time devoted to installation. Finally, the new system higher efficiencies reduce energy costs for the building owner, simultaneously decreasing ventilation and air-conditioning requirements for the machine rooms.

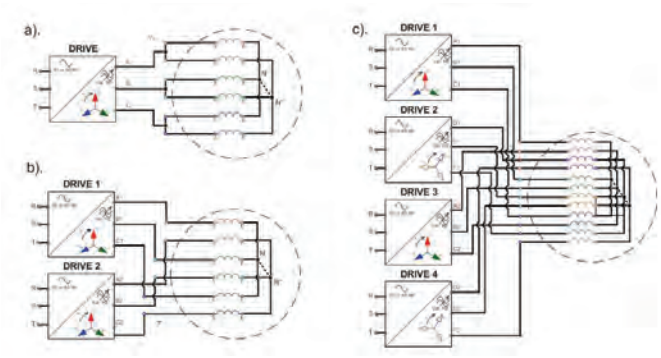

Figure 6. Selected Electric connections of motor and drive for: a). SkyMotionTM 250 machine in one drive 3-phase arrangement; b). SkyMotionTM 400 machine in two drive 3-phase arrangement; c). SkyMotionTM 800 machine in four drives 6-phase arrangement, (Source: Otis Elevator Company)

图6. 为如下设置选定的电机和驱动装置的电气连接: a) SkyMotionTM 250机器，在一驱三相布置中; b) SkyMotionTM 250机器，在二驱三相布置中; c) SkyMotionTM 800机器，在四驱六相布置中 (资料来源: 奥的斯电梯公司)

结论

新型SkyMotion™系统大幅提高了超高层电梯的性能，达到业内目前尚不具备的水平。所用的动力总成使电梯能够驱动双层或三层轿厢，使运行速度达到15米/秒，提升高度达到600米。另外，SkyMotion™ 400系统允许电梯的额定速度达到20米/秒。

由于SkyMotion™ 动力总成的尺寸缩减，使得所需机房的尺寸也缩减，使提升设备的安装更简单，继而也为高层建筑的设计师提供了更大的自由设计空间。由于机器重量减少，也使硬件的尺寸减小、成本和物流费用降低，节约了安装用时。最后，新型系统的更高效能使建筑物所有者降低了能源费用支出，同时也减少了机房的通风和空气调节需求。