New NADCAP Requirements for Temperature Uniformity for Vacuum Heat Treatment according to AMS 2750D

NADCAP 依据 AMS2750D 标准对真空热处理温度均匀性的新要求

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（注：NADCAP 是“国家航空和国防承包商认证程序”的缩写）

In conjunction with constant technological development in the aerospace industry field, the requirements set for equipment for heat treatment have increased, particularly in the area of temperature uniformity precision, the repeatability of results, and the proper archivization of results. Much attention is also being given to processes for facilitating the attainment of the proper balance between advanced technologies and their economic aspects. This places new demands in the coming years on the suppliers of vacuum furnaces, and it creates the need to adapt furnace design to the changing requirements and expectations of the market。

配合航空工业领域技术的不断发展，对热处理设备的要求也相应提高，特别在温度均匀性精度、热处理结果的重复能力、以及适当的其结果编档保存方面。人们更关注设备程序上要达到技术先进，和其经济上合理的平衡。近几年真空炉的制造商都将这些作为新的要求，迎合对炉子设计的改进和市场的期望，而创造出相应的提高。

The majority of world manufacturers and contractors operating in the aerospace industry are associated with the international program *Nadcap*, which was begun in 1990 by the PRI (**P**erformance **R**eview **I**nstitute), an outgrowth of the SAE organization. This program was designated initially as NADCAP, an acronym for **N**ational **A**erospace and **D**efense **C**ontractors **A**ccreditation **P**rogram. Currently, in order to lend the program an international character, only the acronym *Nadcap* is used.

航空工业方面大多数的世界制造商和承包商在国际 NADCAP 规划下组织一起，这个组织是 1990 年由 PRI（性能审查协会）开始的，是 SAE（美国汽车工程师学会）派生形成的。它最初定名为 NADCAP，是国家航空和国防承包商认证程序的缩写。现在为了借用这个程序的国际性质，仅用其首字母缩写为 Nadcap.

Within the *Nadcap* framework, the primary manufacturers of aerospace equipment aim toward technological development and increase the quality of products among their contractors (subcontractors) by imposing strict process and procedures requirements. The *Nadcap* development plan establishes the total elimination of unaccredited contractors in this program over the course of the next few years. Growing number of subcontractors worldwide stimulated by new production programs (e.g., the Airbus A380, the Boeing 787 Dreamliner), requite adaptation of strict quality procedures.

在 Nadcap 的构架下，主要的航空设备制造商的目的是提高技术；再者就是严格程序和步骤的要求，使承包商（转包商）提高产品的质量。在以后的几年，

Nadcap 发展计划确定排除全部未经认可的承包商。受新生产规划（例如：空客 A380，波音 787 梦班机）的激励，不断增加的转包商也要求其严格的质量步骤。

In the field of heat treatment, the program of annual *Nadcap* audits is based on inspection list AC7102, prepared in compliance with the SAE AS7102 standard (National Aerospace and Defense Contractors Accreditation Program -- REQUIREMENTS FOR HEAT TREATING), which were developed in 1993 and were revised in 1995:

在热处理领域，年度 Nadcap 审查以检查 AC7102 目录为基础，遵从 SAE AS7102 标准（国家航空和国防承包商认证程序---热处理要求），其是 1993 年实施并在 1995 年修改的：

AS7001 National Aerospace and Defense Contractors Accreditation Program (NADCAP) - Program Description; (NADCAP)-程序描述

AS7002 National Aerospace and Defense Contractors Accreditation Program (NADCAP)- Rules for Implementation; (NADCAP)-执行规则

AS7003 National Aerospace and Defense Contractors Accreditation Program (NADCAP)- Program Operation; (NADCAP)-程序操作

AS7101 NADCAP-Requirements for Accreditation of Materials Test Laboratories;
NADCAP- 对材料检测实验室条件的要求

AS7102/1 NADCAP-Requirements for Heat Treating Accreditation Programs-
Brazing Requirements;
NADCAP -对热处理鉴定程序要求—钎焊要求

AMS 2750D Pyrometry;
测高温

AMS2801 Heat Treatment, Titanium Alloy Parts;
热处理，钛合金部件

AMS 3025 Polyalkylene Glycol Heat Treatment Quenchant;
聚二醇、乙二醇热处理淬火 ant

ARP1820 Chord Method of Evaluating Surface Microstructural Characteristics
评价表面显微组织特征的弦方法

ARP1962 Certification of Heat Treating Personnel.
热处理人员资质

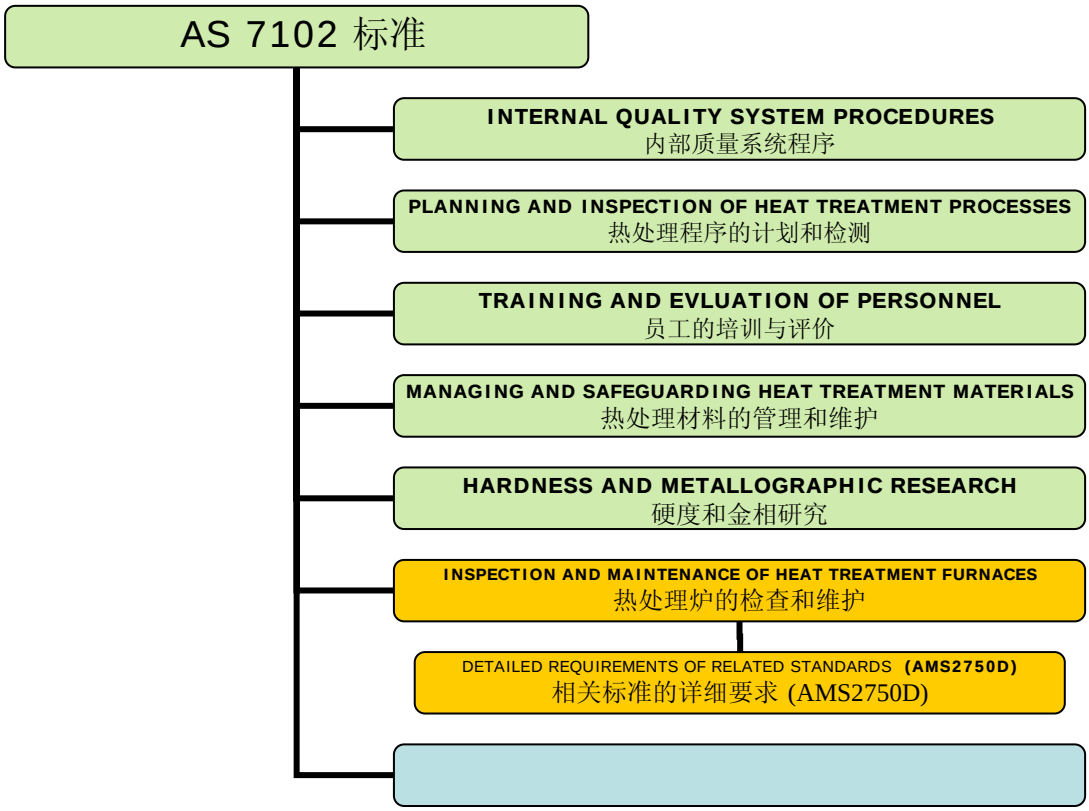
Aerospace standard AS7102 defines requirements for contractors working toward *Nadcap* accreditation in the field of Heat Treatment, issued according to the following algorithm:

航空标准 AS7102 详细说明承包商的热处理工序要遵从 Nadcap 的要求，根据以下的运算法则发布：

Contractors who are seeking to acquire Nadcap accreditation develop internal operating procedures based upon the recommendations of the AS7102 standard. These recommendations cover:

希望获得 Nadcap 鉴定合格的承包商，在内部操作步骤上要符合 AS7102 标准的建议。这些建议是：

- development of internal Quality System procedures;
  内部质量系统程序的发展
- planning and inspection of Heat Treatment processes;
  热处理程序的计划和检测
- training and evaluation of personnel;
  员工的培训与评估
- managing customer materials designated for heat treatment and safeguarding them properly;
  对顾客热处理材料的合理设计和维护
- researching surface hardness, metallographic hardness, micro hardness, and the like;
  研究表面硬度，金相硬度，显微硬度等等
- servicing, inspection, and maintenance of heat treatment furnaces.
  热处理炉的服务，检测和保养维修



In the field related directly to heat treatment furnaces, requirements have been defined primarily related to:

直接与热处理炉相关的方面，主要基本详细要求是：

- guaranteeing and documenting the precise heating speed, the holding temperature and the cooling speed of heat-treated materials or parts;

  保证和归档记载：准确的加热速度，热处理材料或部件的保温温度和冷却速度

- periodic inspection of temperature distribution (uniformity) in the usable area of the furnace;

  定期检查：使用期间炉子各个区域的温度分布（均匀性）

- inspection of the accuracy of the measuring system (temperature sensors, test tracks and reading, regulating and recording equipment);

检查：测量系统的精确性（温度传感器、测试轨迹和读数、校准和记录设备）

- periodic calibration of testing equipment;

周期性校准：检测设备

- inspection of buildup (pressure increase) for vacuum furnaces;

检查：（由于压力增加）真空炉的杂质

- inspection of purity of cooling gas for vacuum furnaces with gas cooling;

对于带有气冷的真空炉，检查冷却气体的纯度

- planning of periodic prevention reviews and their scope and documentation.

定期的预防/评估计划，及其范围和文件

In the area of requirements related to the accuracy of temperature regulation and uniformity, standard AMS2750 (**A**erospace **M**aterial **S**pecification) is used most often. It was issued by SAE (**S**ociety of **A**utomotive **E**ngineers) in 1980. The most recent revision AMS2750D appeared in September, 2005. It introduces stricter requirements for temperature measurement, inspection and recording equipment in furnaces installed after September 2006.

关于温度校准精度和均匀性的要求，通常在 AMS2750（航空材料性能）标准中已经有所说明。它是 SAE（汽车工程师学会）在 1980 年公布的。在 2005 年 9 月推出了最近修订版 AMS2750D。在 2006 年 9 月后介绍了有关对炉子安装后的温度测量、检查和记录仪的严格要求。

It is worth noting that a classification for furnaces was introduced in the AMS2750D with regard to minimum requirements for temperature uniformity in the work area:

值得说明的是在 AMS2750D 里，介绍了对各级别炉子分类、而对工作区温度均匀性的最小要求。

Furnace class 炉子分类级别	**Temperature uniformity (°C)** 温度均匀性
1	± 3
2	± 6
3	± 8
4	± 10
5	± 14
6	± 28

The equipment developed to date at standard ±5°C was thus in class two. Thus, furnace manufacturers are now faced with the obligation to meet the class 1 requirements in their standard products.

到目前为止分类在级别 2 的炉子，其温度均匀性标准在±5°C。那么，炉子制作商现在面临的任务是使炉子的温度均匀性标准符合级别 1 的要求。

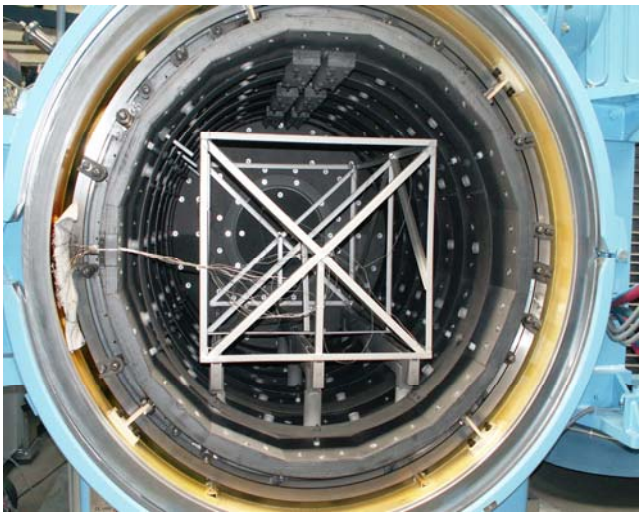


Photo. 1

Temperature distribution study in accordance with the requirements of standard AMS2750D. Seco/Warwick 10.0VPT-4050/60HV universal vacuum furnace with usable area dimensions of 36”Wx32”Hx60”L (900x800x1500mm.)

照片 1

符合 AMS2750D 标准要求温度分布的研究。赛科/沃克 10.0VPT-4050/60HV 型通用真空炉，其有效使用尺寸是 36”Wx32”Hx60”L (900x800x1500mm.)

In its revised version, standard AMS2750D imposes upon furnace users the duty of periodically inspecting the accuracy of the temperature measuring system. The so-called SAT (**S**ystem **A**ccuracy **T**est) tests are done with a frequency that depends upon the furnace class and the type of measuring equipment used in it ("A" or "E"). In the case of the vacuum furnace type classed as 2D, the SAT test should be performed weekly. End users of vacuum furnaces from the aerospace industry are expecting a new design solution in the area of measuring sensors, recording and thermocouple feedthroughs, in order to optimizing this procedure.

在修订版里，AMS2750D 标准加强对使用者在炉子运行期间检查温度系统精确度的责任要求。所谓 SAT 检测（系统精确度的检测），其操作检测的频率主要依据炉子的级别和测试设备的类型（A 或 E）而定。在真空炉子类型级别分类为

2D 的情况下，SAT 要求每周检测一次。航空工业真空炉使用者希望设计一个新检测传感器、记录仪和热电偶馈入装置等的方案，这样是为了优化完善这个步骤。

Photo. 2
Dual "S" type thermocouple (Controlling and Over-Temperature) adapted to the requirements of SAT inspection procedure in compliance with AMS2750D.
图片 2
双芯“S”型热电偶（控制和超温）适合 SAT 检测的要求，并符合 AMS2750D 标准。

Photo 2 presents one of the solutions used in Seco/Warwick furnaces. The so-called "nonresident" SAT thermocouples may be inserted at any time, including during the course of the production process into an impermeable thermo-well built into the regulatory-safeguarding thermocouple in the illustration.

照片 2 展示 1 个赛科/沃克炉子的解决方法。所谓的“非固定”SAT 热电偶可以随时插入炉中。包括在生产过程中插入密闭的热-井结构中，可调整-保护式热电偶。如图所示。

The use of a tight cork safeguards the heating chamber of the furnace against oxidization in the event of a mechanical failure of the thermo-well.

使用密闭塞子装置在热-井结构发生机械故障事件时，防止炉子加热室氧化。

Vacuum furnaces for materials or subassembly heat treatment utilized in the aerospace industry should also meet the following general requirements [1]:

航空工业领域的真空炉对材料或部件热处理时，要符合以下常规要求[1]：

- maximum vacuum (empty and cold furnace after degassing) in the range of 10^{-6} Torr,

极限真空度（排气后空炉和冷炉）在 10^{-6} 毛的范围

- working vacuum at a level of 10^{-4} - 10^{-5} Torr,

工作真空：10^{-4} - 10^{-5}毛水平，

- high accuracy of regulation, and temperature uniformity during heating and cooling,

在加热和冷却时，高精度调节和温度均匀性

- heating capacity of furnace sufficient for heating the charge through the range of temperatures of technological utilization with a speed of 20^{o}C/min to 40^{0}C/min for example.

炉子对工件有充足的加热能力，在技术使用范围中，实际加热速度是每分钟摄氏 20-40 度。

- cooling time of the charge from a temperature of 1100^{0}C to 540^{o}C, for example, for the array of parts used in these industries, at a maximum level of 6 min, which is normally reached in furnaces with a cooling gas pressure of 1.5 bar abs.

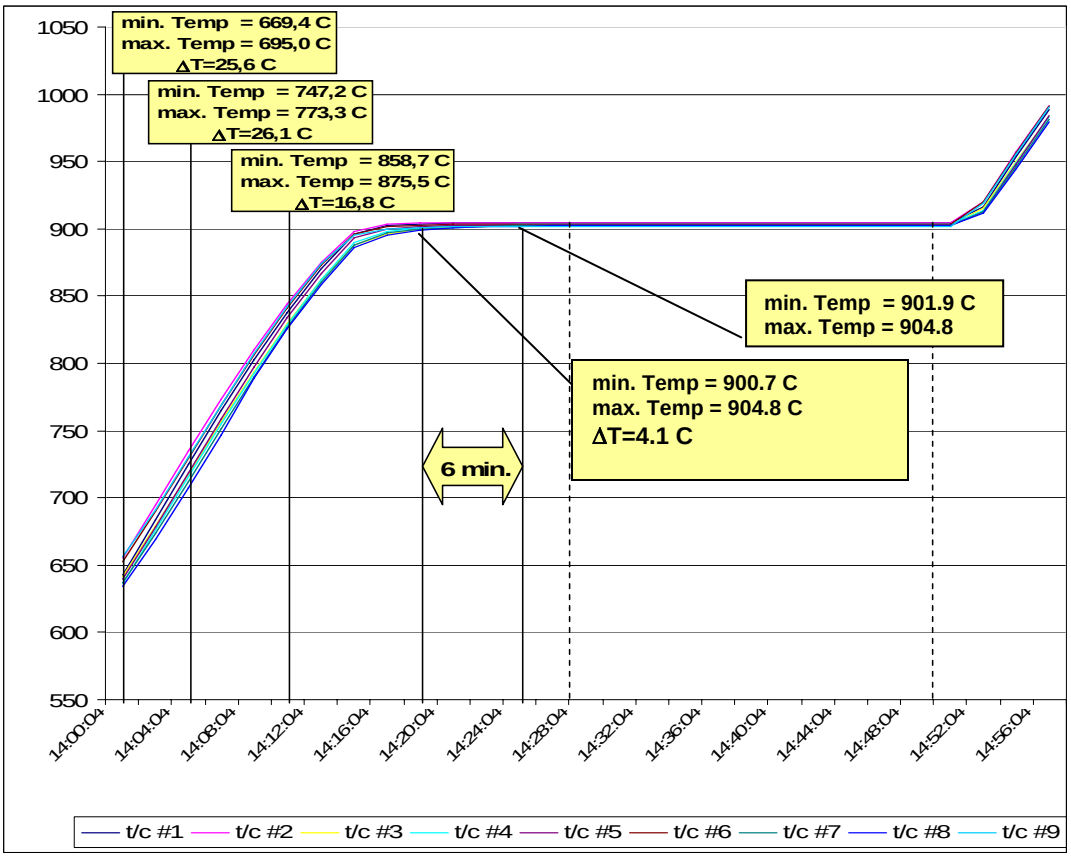
例如在炉中排列的工件，在 1.5 巴绝对压力冷却气体下，工件从温度 1100 度冷却到 540 度的冷却时间，最多用 6 分钟。

- cooling of the charge with inert gas, most often argon (Ar), with a purity of at least 99.999%.

用惰性气体冷却工件，通常是纯度至少 99.999%的氩气

In the figure inserted below, sample results of temperature uniformity researched in compliance with AMS2750D are presented, during the segments of heating and holding at a given temperature.

如下图所示，在给定温度菜单下加热和保温的工件，呈现的温度均匀性符合 AMS2750D 标准。



The standard vacuum furnace for the aerospace industry yields results of approx. ±10°C in temperature uniformity during the course of heating and below ±3°C during the holding segment. The temperature stabilization time following the beginning of the holding segment is approx. 5 min until the range of ±5°C is reached and another 5 min. until total temperature stabilization at a level below ±3°C) is achieved. This feature is especially important for a quality brazing processes.

航空工业领域的标准真空炉，在加热时温度均匀性大约是±10°C、而在保温时温度均匀性小于±3°C。温度稳定的时间，从保温阶段开始计算约 5 分钟后达到±5°C 温度均匀性范围，然后再经过一个 5 分钟获得整体温度均匀性好于±3°C 水平。这个特性对工件钎焊质量方面很重要。

Heat-retentive alloys of nickel and cobalt, austenitic and martensite stainless steels, and titanium alloys are use in the aerospace industry.

镍/钴硬磁性合金、奥氏体和马氏体不锈钢、和钛合金都用在航空工业上。

For brazing processes, two furnace designs are currently offered: furnaces with metal (shield) insulation or furnaces with insulation made up of graphite composites.

在钎焊处理中，通常提供设计两种炉子：带有金属隔热屏的真空炉、或是带有石墨隔热屏的真空炉。

Photo. 3

Seco/Warwick type 6.OVP-4050/48MHV vacuum furnace with 6 bar cooling capability and all metal insulation and moly heating elements.

照片 3

赛科/沃克 6.OVP-4050/48MHV 型真空炉、6 巴冷却压力、全金属隔热屏和钼镧加热元件

A typical feature of vacuum furnaces with metal insulation is somewhat higher heat losses at a high temperature (for example1200^{o}C heat losses are approx. 10-11 kW/m^2) in comparison to graphite chambers. After a certain period of utilization (depending upon the "purity" of heat treat processes), these losses increase to a level of up to 15-16 kW/m^2. Such changes in heat losses over time means that it is significantly more difficult to maintain the temperature uniformity and increases energy consumption during heat treatment cycles. The design of heating zones, heating elements and for the manner of placement of heating elements are of key significance to the technological properties of these furnaces.

与石墨隔热屏炉室相比较、全金属隔热屏真空炉的一个典型特征是，在高温下损失的热量会多一些（例如 1200^{o}C热量损失是大约 10-11 kW/m^2) 。炉子经过一段时间的使用后（决定于热处理过程的“净化”程度）这个损失增加到 15-16 kW/m^2 。随炉子使用时间延长而热损失的这些变化，意味着在热处理周期保持炉温均匀性是相对很困难的、并增加了能量消耗。因此炉室加热区的设计、加热元件在加热室中的布置，是决定这些炉子技术性能的关键重点。

The cost of a heating chamber with all metal insulation is higher than that of a heating chamber with graphite insulation. Moreover, to ensure the certainty of obtaining a temperature distribution over a long period of utilization, it is sometimes necessary to use zone regulation, adding heating elements to the door and the back wall, will increase the investment and utilization cost. With the proper quality of materials for the insulation wall, and properly selected vacuum pumps, graphite insulation likewise ensures the level of the working vacuum at the level of $10^{-4} \div 10^{-5}$ Torr and the maximum vacuum of even at 10^{-6} Torr range.

全金属隔热屏加热室的成本要比石墨隔热屏加热室的成本高。而且，为了确保长期使用后获得一定的温度均匀性分布，有时必须对加热区进行校准、另外在炉门和炉后墙增加加热元件，这样会增加炉子的投资和使用成本。如果选择了合适的隔热屏材料和适当的真空泵，石墨隔热屏同样可以确保 10^{-4} - 10^{-5} 毛工作真空度水平、和 10^{-6}毛范围的极限真空度水平。

Graphite materials for constructing of the insulation and the heating elements play an essential role. Properly constructed heating chamber graphite insulation is characterized by a significantly lower level of heat loss compared to that of furnaces with metal shield insulation. For the typical sizes of furnaces, heat loss is 6-7.5 kW/m^2 at 1200^{o}C. In practice, the level of these losses does not change over the course of a 10-year period of utilization of the furnace, which significantly differentiated this type of insulation from metal shield insulation. For this reason, periodic certifications of temperature distribution are just as accurate as in an initial test, and the requirements relative to solutions in the area of managing heating zones are simplified.

石墨材料结构的隔热屏和加热元件，担负了真空炉种类的重要部分。合理结构的加热室石墨隔热屏与金属屏相比，以较低的热量损失为特点。对于典型尺寸的炉子，在炉温 1200 摄氏度时热损失是 6-7.5 kW/m^2。 实际上炉子使用了 10 年，不会改变这个热损失水平，这一点有别于金属隔热屏。因此石墨隔热屏的温度分布保障与炉子最初检测是一样的精确，简化解决了对加热区域的要求。

Photo. 4
Seco/Warwick 2.OVPT-4050/48HV vacuum furnace with a graphite heating chamber.
照片 4
赛科/沃克 2.OVPT-4050/48HV 型带有石墨隔热屏加热室的真空炉

In the design of Seco/Warwick vacuum furnaces with graphite insulation, heating chambers of a cylindrical configuration with curve graphite heating elements are used 360^{o} around the charge.

赛科/沃克设计的带有石墨隔热屏的真空炉，圆柱形加热室、带有片状弧形石墨加热元件（在工件周围 360 度分布）。

The cylindrical hot zones provide better and more consistent temperature uniformity over long period of time (according to AMS 2750D class 1 requirements) compare to rectangular chambers with rod or tube heating elements especially after prolong usage.

与带有棒/管状加热元件的矩形加热室相比，圆柱形加热室提供更好的温度均匀性（根据 AMS2750D 级别 1 类要求），尤其炉子在长期使用后（更明显）。

Moreover: 此外

- wide and light heating elements make it possible to heat the charge with very low surface loads [W/cm^2]. Unlike the solutions with rod heating systems generally in use in Europe, this ensures that the above-mentioned "close connection" of the non-uniform approach of the temperature of the charge to the holding temperature is attained, which is more often required in rapid heating processes;

宽而轻的加热元件可以用非常低的表面负荷[W/cm^2]加热工件。不像欧洲现在通常使用的棒状加热系统，这确保了使上述非均匀温度的工件密切衔接以获得保温的温度，此点在快速加热过程中常常需要。

- a very light heating system makes possible a high rate of heating and cooling of the charge, fulfilling the requirement for heating with speeds in the range of of 40^{0}C/min.

非常轻的加热系统能够高效率地加热和冷却工件，实现 40^{0}C/min加热速度的要求。

- good access to the heating chamber area during loading in and loading out. Work with additional charge thermo elements is also facilitated.

在装料/卸料时，工件进/出加热室。也安装附加的加热元件。

- circular construction of the heating chamber is relatively stable during the heating and cooling cycles over a period of long-term utilization of the furnace.

炉子在加热和冷却周期中长时期使用后，加热室的圆形结构仍是稳定的。

In conjunction with constant technological development in the aerospace industry field, the requirements set for equipment for heat treatment have increased, particularly in the area of temperature uniformity precision, the repeatability of results, and the proper archivization of results. Much attention is also being given to processes for facilitating the attainment of the proper balance between advanced technologies and their economic aspects. This places new demands in the coming years on the suppliers of vacuum furnaces, and it creates the need to adapt furnace design to the changing requirements and expectations of the market.

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