

Engine Construction I 柴油机结构

Traditional Engine Structure 传统柴油机结构

A traditional engine structure arrangement comprises a cylinder block which accommodates the cylinder liners, the block differs in design depending on whether the engine is of in-line or Vee form. The block has spaces to accommodate camshaft drive arrangements (chain or gear), a housing for the camshaft and doors allowing access to the crankcase. The block is a single casting to ensure rigidity. Cast iron is the usual material. Supporting the cylinder block is the bedplate with its main bearing housings and mounting feet, which connect to the ship's structure. In some cases tie rods are employed to maintain the main bearing housings and engine block in compression. The steel tie rods pass from the upper part of the cylinder block to the lower face of the bedplate below the main bearing housing. Smaller engines often have no tie rods as the structural section thickness is great enough to keep tensile stresses reasonable during peak pressure periods. With a casting there is a minimum section thickness requirement to ensure that the molten metal flows readily to all parts and this thickness is often greater than that dictated by actual stress considerations. Accurate alignment between bedplate and cylinder block is essential to effective stress transmission and engine operation.

传统柴油的结构中包含有一个用来安装汽缸套的汽缸体，发动机是直列式布置还是 V 型布置就造成了汽缸体设计形式上的差异。机体结构有用来容纳凸轮驱动机构（链条或齿轮）、凸轮轴和进入曲轴箱道门的空间。为了保证刚度，机体结构通常是由铸铁材料铸成一个整体。机座上面安放有汽缸体，其上面带有主轴承座和把机座固定到船体机构上的地脚。有些情况下，用贯穿螺栓以一定压力把主轴承座和汽缸体连接在一起，钢制的贯穿螺栓从汽缸体的上部一直通到机座的下表面（主轴承下部）。小型柴油机没有贯穿螺栓，因为其构件的厚度足够克服由于最高爆发压力所产生的张力。如果是铸铁机体的话，就很少有构件厚度方面的要求，为了保证熔化的铁水能够容易地流到所有的部位，构件的厚度一般要比能承受实际应力的厚度大得多。机座和汽缸体之间正确调整，对于柴油机的有效传递以及柴油机的正常运转都是非常必要的。

Modern Cast Monoblock Structure 现代整体铸造结构

Engines designed during the 1990s generally employ a cast monoblock form of construction with the cylinder block and bedplate forming a single cast iron structure. This nodular iron casting provides considerable rigidity due to its single-piece design and construction. In some engines additional strengthening can be provided by long tie rods extending from the lower face of the main bearing to the upper part of the structure. Tie rods are also employed between the upper face of the cylinder head and the lower face of the intermediate frame structure to ensure that combustion loads are transmitted from the cylinder head to the engine frame structure. The use of tie rods does not imply a weakness in design and is an effective use of a strengthening mechanism where it is needed. A rigid structure is necessary in order to preserve alignment of all engine parts, particularly the crankshaft and camshaft, and to minimize problems related to vibration of the structure. Some engines (e.g. Wartsila Vasa 38) have the air inlet manifold as an integrated part of the engine block while many water and oil channels are cast-in or machined as part of the engine structure. Such features make for easier maintenance, improved accessibility and a reduction in the number of engine parts.

在 20 世纪 90 年代，柴油机设计开始运用整体铸造结构，把汽缸体和机座一起铸造成一个铸铁构件。由于设计和构造上的整体性，使得球墨铸铁件非常的坚固。一些柴油机还利用长贯穿螺栓从主轴承的下表面通到构件的上部为整个机体进行额外加强。贯穿螺栓也用在汽缸头的上表面和机架的下表面之间，以保证把燃烧负荷从汽缸盖传到机架上。使用贯穿螺栓并不是意味着设计上存在缺陷，而是在需要的地方有效地利用加强机构。一个刚性结构应该保证主机各部件，尤其是曲轴和凸轮轴的精确位置，将结构的振动问题降到最低。一些机型（如：Wartsila Vasa 38）将进气总管与机体集成在一起，而水和油的通道则采用铸造或车削后，做为机体结构的部件。这样设计特性简化了维修保养，提高了可达性，降低了主机部件的数量。

With monoblock structures, a sub-frame is required to act as the engine sump. This sub-frame, which bolts directly to the lower face of the engine structure, takes no load and can be manufactured from welded plate. Lubricating oil suction pipes and strainers are arranged within the sump.

对于整体结构来说,下部结构被用作柴油机的油底壳。油底壳用螺栓直接连接到主机整体结构的下表面上,不承受负荷,可用金属板焊接制成。润滑油的吸入口和过滤器都安装在油底壳中。

Main Bearings 主轴承

Main bearing support housings are cast as part of traditional bedplate arrangements, and these combine adequate rigidity for the crankshaft with relative ease of bearing adjustment.

主轴承座作为传统机座的一部分也是铸铁的,轴承座和机座具有足够的刚度,这样轴承的调整就相对容易

Bearing replacement requires lifting the bearing cap, which is held from above with studs and nuts.

轴承更换的时候需要卸下轴承盖,轴承盖是从上部用螺栓螺母固定的。

Although this type of arrangement can, in theory, be incorporated within a monoblock engine structure, it is not used. An underslung main bearing support system is preferred. Nodular cast-iron bearing caps are held from below by means of two hydraulically tensioned studs.

尽管理论上可把这种设计的轴承盖与整体式机体结构做成一体,但实际中并不这样做。一般首选悬挂式的主轴承支撑系统,球墨铸铁轴承盖利用两个液压张紧螺栓从下面固定。

These bearing caps are guided laterally into the engine block at the top and bottom and the hydraulic jacks are often permanently fitted to allow for ease of maintenance. Hydraulically tensioned horizontal side studs support the main bearing caps and with the vertical studs and lateral guide arrangements provide a very rigid main bearing support for the crankshaft.

主轴承盖可从上部和下部横向导入机体结构,为了方便维护保养经常安装固定式的液压千斤顶。水平布置得液压张紧螺栓支撑主轴承盖,再加上垂直螺栓和侧向楔形块,就给曲轴的轴承提供了一个很大刚性的支撑。

Main bearings for medium speed engines currently in use are of the thin shell type. 中速机普遍使用薄瓦性的主轴承。Similar bearing shells are employed for bottom end bearings.底部轴承也利用相似的轴瓦。This type of bearing essentially consists of a thin steel backing shell with a layer, or layers, of bearing material cast, flashed or deposited on the rubbing surface. 这种类型的轴瓦基本上是在薄钢衬壳内部的粗糙的表面上浇注或沉淀一层或多层的轴承材料。This type of bearing is prefinished and does not require scraping to fit; indeed no scraping is possible due to the thin layer of bearing material present. 这种类型的轴承只需要表面抛光,不需要过多处理,实际上由于轴承材料层很薄没有必要进行刮擦等处理。Over the years bearing materials have changed to meet the operating conditions. 多年来为了满足工作条件,轴承材料进行了不断地改进。Early arrangements simply had a layer of white metal on the steel backing shell but this gave way to the multi-layer bearing with a layer of lead-bronze or copper between the steel and white metal in order to improve adhesion. 早期的轴瓦只是简单的在薄钢衬壳内部浇注一层白合金,但是这种制作方法为多层轴瓦提供了借鉴,多层轴瓦是在薄钢衬壳和白合金之间又加了一层铅青铜或者黄铜来提高金属间的粘着力。This layer also provided an emergency bearing surface. 添加的这一层也提供了一个应急轴承面。The use of overlay material provides a degree of protection against corrosion, while a thin layer of nickel prevents the lead in the overlay from

migrating into the lead-bronze layer 覆镀材料能够对腐蚀提供一定程度的保护, 覆镀一薄层的镍就能够防止铅向青铜层的迁移。The backs of the steel shells may have a soft layer which is designed to prevent corrosion. 钢衬壳也可以加一层软材料防止腐蚀。During the 1990s a number of engine builders returned to bi-metal bearings which employ a layer of aluminium-tin on the steel backing shell. 在 20 实际 90 年代, 一些柴油机厂又从新生产在钢衬壳内部加一层锡铝合金的双金属轴承。Others employ a multiple layer bearing with a tin-antimony rubbing surface over a copper-lead layer on the steel backing shell. 另外一些厂家利用在钢衬壳内部的铜合金层之上又加了一层表面粗糙的锡锑合金生产多层轴瓦。Bearing technology continues to change to meet the demands of higher loads but problems of lubricants contaminated by water and residual fuels must also be overcome. 轴承技术不断发展为满足了更大负荷的需要, 但是还需要克服由于水和残油对润滑油所造成的污染问题。

Crankshaft 曲轴

Crankshafts for medium speed engines are solid forgings from a single alloy steel ingot. 中速机的曲轴是用一块合金钢锭实锻而成的。Solid forging avoids stress problems, which would result from the presence of shrink fits, and ensures even stress transmission between journals, webs and pins. 实锻避免了因收缩配合带来的应力问题, 避免了轴颈、曲柄臂和曲柄销上的应力集中。There are very rigorous Classification Society rules governing the dimensioning of crankshafts, based on a combination of theory and experience. 基于理论和实践经验的结合, 船级社规则对曲轴的尺寸有严格的要求。Current designs make considerable use of computer finite element analysis which allows a wide range of loadings, dimensions and cylinder firing orders to be analysed before any manufacture takes place. 现在的设计利用了计算机有限元分析方法, 在任何生产之前, 都对大负荷范围、不同尺寸和汽缸点火顺序等进行分析。A crankshaft must be able to transmit the torque developed during operation. 曲轴必须能够传递柴油机工作过程中所产生的扭矩。This torque imposes stresses on the crankshaft journals. 扭矩在曲轴轴颈上产生扭转力。Pins are subject to direct stresses from the connecting rods, which impose bending and shear stresses. 曲柄销承受从连杆传来的力, 这个力会在曲柄销上弯曲力和剪切力。Webs bend due to this loading but they also have a tendency to twist. 由于这个负荷曲柄臂会产生弯曲, 但是它们也有一个扭转的趋势。Crankshafts will bend under load as each cylinder unit section acts like a simply supported beam, with the main bearings acting as the supports. 曲轴像一个被简单支起来的梁, 主轴承就像支撑体, 这样曲轴在每一个缸所产生的负荷的作用下就会产生弯曲, Loadings vary with time making the analysis of stresses a complex matter, further complicated by the presence of oil holes through journals, webs and pins. 负荷随时间的变化使应力的分析变得复杂, 轴颈、曲柄臂和曲柄销中钻孔后使应力的分析变得更加复杂

The firing order of an engine is primarily chosen to reduce engine torque fluctuations and minimize vibration. 对于降低扭矩的波动和降低振动, 发动机点火顺序的选择很重要。Any final solution must be something of a compromise as other factors have to be considered including exhaust arrangements, bending loads on the crankshaft and torsional vibration. 任何最终方案都是一个折中选择, 因为排气布置、曲轴上的弯曲负荷和扭转振动等其他因素也要考虑。Reciprocating masses-the pistons, connecting rods, webs and crankpins induce vertical forces which can result in vibration. 往复运动质量, 如活塞、连杆、曲柄和曲柄销都会产生垂直方向上的力, 进而导致振动。Reducing the mass of these components through the use of lighter materials and removal of all unnecessary materials will help to minimize vibration but will not eliminate the problem. 通过使用轻金属和去除不必要的材料都会降低这些组件的质量, 减轻

振动, 但不会消除这个问题。Most medium speed engine crankshafts are machined all over in order to reduce excess weight. 为了去除多余的重量, 中速机的曲轴需要整体车削。They are provided with adequate fillets at all changes of section in order to avoid stress raisers which could give rise to Fatigue. 为了防止应力集中造成应力疲劳, 在任何横截面积的改变处都加上足够的圆倒角, Changes in section occur between journal and webs, crankpins and webs, and at oil holes. 截面改变一般产生于轴颈和曲柄连接处、曲柄和曲柄销连接处及一些油孔处。In many cases balance weights are fitted to some or all of the webs, these are designed to oppose the vibration induced by the reciprocating masses. 一些情况下, 会在部分或全部曲柄上安装配重, 这些配重用来抑制由往复质量产生的振动。The solution is only partial as a rotary mass will not only induce vertical forces to oppose the reciprocating masses but it will also induce variable sideways forces, causing transverse vibration. 只有部分配重充当回转质量, 这不仅会产生垂直方向上的力平衡往复质量, 还会产生变化的横向力, 引起横向振动。The size and positioning of balance weights are carefully arranged by the designer and should not be changed. 配重的大小和安装位置需要由设计者仔细选择, 并且不应改变。

Connecting Rod 连杆

Connecting rods are forged from alloy steel and machined all over. 连杆是由合金钢锻造并进行车削。The basic connecting rod requires a provision for attaching it to the crankpin, at the bottom or large end bearing, and to the piston at the gudgeon pin, the top or small end bearing. 最基本的连杆在底端或大端轴承处, 需要一个机构把它连接到曲柄销上, 在上端或小端轴承处需要一个机构把它通过活塞销连接到活塞上。The small end generally consists of a bush inserted in a hole bored in the top of the connecting rod. 连杆小端通常在钻孔内安装一个衬套。The bush may be a simple bronze affair but some engines, particularly a high powered unit, have white metal lined, or tri-metal, bushes. 衬套是个简单的青铜件, 但是一些柴油机尤其是大功率的机型, 会在衬套内部再衬上白合金, 或者使用三合金衬套。Lubrication for the top end bearing comes from the crankshaft via the bottom end and a hole drilled in the connecting rod. 给连杆顶端轴承润滑的油, 是由曲轴经过连杆底端和连杆上的钻孔供入的。This passageway is also used to conduct cooling oil to the piston. 这个通道也用来为活塞输送冷却油。Because of the high loadings on the small end bearings and the absence of complete rotary motion, an adequate supply of lubricant is essential at all times. 因为小端轴承的负荷重, 并且缺少完全的回转运动, 所以在任何时候向小端输送足够的润滑油是非常重要的。Stepped small end bearings are used to provide a large bearing surface on which the piston force may act via the gudgeon pin. 用踏板轴承提供大的承载表面, 活塞力经活塞销传到小端。

The large end bearing of connecting rod can present certain maintenance problems. 连杆大端轴承也会出现维护保养的问题。The traditional fixed centre connecting rod has the upper part of the large end housing forged as part of the rod, which means that the lower part of the connecting rod is wide in order to accommodate the bearing shell and securing bolts. 传统的固定中心式连杆大端的上半部分是和连杆锻造在一起的, 也意味着连杆大端的下半部分是开放式的, 可以安装轴瓦和紧固螺栓。In order to remove the piston, with the connecting rod still attached, the bottom part of the connecting rod must be no wider than the cylinder bore through which it will be lifted. 为了能够在连杆不拆除的情况下吊起活塞, 连杆底部不能够比缸套内径大, 这样活塞可以通过缸套吊出来。Modern engines employ large diameter crank pins in order to provide large area bearings and low bearing loads. 现代柴油机采用大直径的曲柄销来提供大的承载面积, 降低轴承单位负荷。A fixed centre connecting rod design would not be suitable. Alternative arrangements are available. 固定中心式设计将不是一个合适的备用方案。

Bearing shells for large end bearings are similar to main bearing shells but are provided with large oil holes in a central channel. 连杆大端轴瓦和主轴承的轴瓦相似，但是会在中心油路加大润滑油的供给。These allow oil to flow from holes in the crankpin, through the bearing, to passageways in the large end and then up the hole in the connecting rod. 这样润滑油就会通过曲柄销上的油孔、主轴承、连杆大端上的通路向上流向连杆中的油路。Tags on the bearing halves mate with location points in the housings ensure correct alignment. 轴瓦上的销钉和轴承座上的点相对应，保证正确的定位。As with main bearings the thin shells rely on the accuracy of the bore machined in the large end to preserve a true circular shape. 连杆大端内孔的精确加工，对于薄的轴瓦保持圆环形起决定作用。Correct tightening of the large end bolts is, therefore, essential. 因此，大端连接螺栓的正确紧固也是很重要的。

The articulated connecting rod arrangement has a single large end bearing block to which both connecting rods are attached. 主副连杆式连杆（又称关节式连杆）有一个单独的大端轴承体，主副连杆连到轴承体上。The master rod is connected rigidly by means of a palm end, while the slave rod is attached by an articulated arrangement, such as a pin and bush. 主连杆通过平的端面刚性连接到轴承体上，副连杆通过一个销和衬套的铰链机构连到轴承体上。This is necessary because the motions of both pistons, and of their connecting rods and large ends, differ as the crank rotates. 当曲轴回转的时候，由于两个活塞、它们的连杆和大端的运动是不同的，所以这种设计是有必要的。The articulated large end arrangement has cylinder centre in line across the engine and both pistons may be removed without touching the large end bearing. 铰链式大端的设计（主副连杆式结构），主机各个缸的中心线在同一平面上，两个活塞都可以在不影响大端轴承的情况下拆除。

LESSON 4

Engine Construction II

PISTONS AND PISTON RINGS 活塞、活塞环

Pistons for medium speed engines must be capable of withstanding the gas loads experienced during peak firing periods without any appreciable leakage. 中速柴油机的活塞必须能够承受最高燃烧时所产生的气体负荷，并且没有明显的漏泄。As a result the sealing arrangements provided by the piston rings must be effective, even though lubrication at the top of the cylinder may be marginal. 即使是汽缸的顶部润滑油的量较少，活塞环也必须达到密封效果，Unlike crosshead engines most medium speed engines rely on splash lubrication from the crankcase, which must be controlled by scraper rings located on the piston crown or on the skirt. 不像十字头式柴油机，许多中速柴油机采用飞溅式润滑，润滑油量通过位于活塞头或活塞裙上的刮油环来控制。A skirt is necessary on two stroke cycle engines in order to seal the ports when the piston is at the top of its stroke. 二冲程柴油机必须设有活塞裙，当活塞位于行程顶部的时候用来关闭气口。In a four stroke engine, the skirt also guides the piston into the cylinder, countering the side thrusts caused by the angularity of the connecting rod. 在四冲程柴油机中，活塞裙在汽缸中起导向作用，并且承受由于连杆倾斜所产生的侧推力。

A piston assembly consists essentially of the piston crown, the skirt, a gudgeon pin and a number of piston rings. 活塞的主要组件有活塞头、活塞裙、活塞销和一些活塞环。The crown is subject to the highest combustion pressure and thermal load. 活塞头承受燃烧所产生的高温

高压, It may also suffer from impingement by the combustion flame if the atomiser spray is defective. 如果雾化器效果差的话, 还需要经受火焰的冲击。Piston crowns are of the dished type to provide a combustion chamber between the piston crown and the cylinder head. 活塞头是中凹形的, 与汽缸盖形成燃烧室。To give the desired combustion, the shape of the bowl formed in the crown depends on many factors, including the choice of atomiser spray. 良好的燃烧效果取决于很多因素, 包括活塞头的形状和喷油器的选择。The flat rim of the piston surrounding the dished combustion chamber generally contains cut-out sections to prevent the piston from hitting the inlet and exhaust valves. 活塞中凹形顶部的圆环面上通常有凹坑用来防止进排气阀撞击到活塞。The piston crown is generally made from high quality, deformation resistant forged steel and contains internal cooling surfaces and the provision for a number of piston rings. 活塞头通常采用质量好且耐变形的锻钢制作, 其内部有冷却空间, 外部有安装活塞环的环槽。The crown may taper slightly in order to allow for thermal expansion while in service. 活塞头可以有轻微得锥度, 以适应其工作时的热膨胀。During operation the upper part of the crown becomes hotter than the lower part so it will expand more. 在工作时, 活塞头上部会比下部热, 所以也膨胀的多。Tapering allows a narrow clearance between piston and liner to be maintained. 这个锥度就使得活塞和缸套之间保持一个小的间隙。

批注 [s3]: 语序有问题

批注 [s4]: 外部有环槽

A piston skirt guides the piston in the cylinder, minimising the tipping of the piston which causes high contact pressures at upper and lower parts of the piston/skirt assembly and disturbs gas sealing of the rings. 活塞裙引导活塞在汽缸中运行, 减轻活塞的倾斜。倾斜会引起活塞上部和下部组件产生高接触压力以及破坏活塞环的密封。The piston skirt is subject to lower thermal and mechanical loads than the crown and can be made from materials of lower strength. 活塞裙所受的热负荷及机械负荷都比活塞头低, 可以用低强度的材料制作。It is subject to greater rubbing against the liner, however, and should have a lower coefficient of friction. 活塞裙与汽缸套之间摩擦严重, 最好选用摩擦系数低的材料, Nodular cast-iron is often used for piston skirts due to its low coefficient of friction and ability to be readily cast into a fairly complex shape. 球墨铸铁的摩擦系数较低, 并且能够很容易救助造成复杂形状, 所以经常采用球墨铸铁制作活塞裙。Aluminium is also used for piston skirts. Its low density is an advantage in terms of inertia forces, although it has a higher coefficient of thermal expansion than nodular cast iron. 铝也经常用来制作活塞裙, 虽然它比球墨铸铁的热膨胀系数大, 但是由于它的密度低利于减小惯性力。At low loads an aluminium skirt will give increased cylinder clearance compared with one of nodular iron, so the piston axis will differ slightly from the cylinder axis. 与球墨铸铁的活塞裙相比, 铝制活塞裙在低负荷时的汽缸间隙较大, 所以活塞的轴线会稍微偏离汽缸中心线。At reduced loads an aluminium skirt will therefore not provide as stable a platform for the piston rings as a nodular iron skirt. 负荷降低时, 铝制活塞裙不会像球墨铸铁活塞裙那样为活塞环提供一个稳定的平台。The skirt does not need to be perfectly cylindrical, as long as it is shaped to assist the formation of an effective lubricant film between piston and liner. 活塞裙不必要加工成一个理想的圆柱体, 只要他能够在活塞和汽缸套之间形成一个有效地润滑油膜就可以。Some skirts taper slightly from bottom to top while others are of oval section, with the minor axis parallel to the axis of the gudgeon pin. 一些活塞裙会从底部向上有一个锥度, 一些会有椭圆横截面, 椭圆的短轴平行也活塞销的轴线。

In most engines the top three rings are classed as compression rings, although the upper ring takes most of the gas loading. 大多数柴油机中最上面的三道活塞环是压缩环(气环) Ring materials should be compatible with the liner material in order to avoid scuffing as the rings rub over the liner surface. 活塞环的材料应该与汽缸套的材料相适应, 避免活塞环擦过汽缸套表

面时造成擦伤。Rings must retain their initial spring at operational temperatures and pressures, resist thermal cracking and maintain their mechanical strength. 活塞环必须在工作压力和温度下保持初始的弹性, 不出现热裂纹并保持机械强度。Ideally they should have some self lubricating properties.理想的情况下, 它们应该有一定的自润滑特性。Cast iron is an ideal material but for modern conditions alloying elements such as manganese, chromium and molybdenum are employed to improve mechanical strength, heat resistance and self-lubrication. 铸铁是一种理想的材料, 现在也把一些合金元素如锰、铬和钼加入到铸铁当中用来提高机械强度、耐热性和自润滑能力。

Cylinder Liners 汽缸套

Cylinder liners are centrifugally cast from nodular or close grained cast iron to obtain good mechanical strength and wear resistance. 汽缸套是利用球墨铸铁或者细晶粒铸铁离心铸造, 已获得良好的机械强度和耐磨性。A rigid liner bore which is free of distortion is ideal and, with the provision of good lubrication, provides optimum running conditions for the piston and piston rings. 理想情况下, 如果有良好的润滑, 活塞和活塞环工作于最佳条件, 一个刚性汽缸套是不会变形的, Liners fit into the cylinder block, but for many highly rated engines the cylinder block does not always house the water jacket which is instead provided by means of a separate unit mounted above the block. 汽缸套安装在汽缸体上, 但是一些大功率的柴油机汽缸体不总是都带有水冷却腔, 而是在汽缸体上部安装一个独立的冷却单元。Such an arrangement provides cooling just where it is required, at the upper part of the cylinder liner, and also avoids the risk of cooling water leaking into the crankcase or of oil from the crankcase gaining entry to the cooling water system. 这样的布置恰好冷却了汽缸套的上部, 避免了冷却水泄漏进曲轴箱和曲轴箱内部的油进入冷却系统的危险。The liner is located within this jacket unit and sealing rings are provided to prevent water leakage. 汽缸套位于水套的内部, 用密封圈防止水漏泄, The jacket unit sits on the cylinder block and is held in place by the cylinder head. 水套安装在汽缸体上, 用汽缸盖定位。Although such jackets may not be shrink fits with the liner they should be neat fits and add strength to the upper part of the liner under working conditions. 尽管水套盒汽缸套之间不是红套安装, 他们也应该配合良好, 当缸套处于工作条件下, 水套应该对汽缸套上部施加一定的力。Individual jackets ensure low cylinder liner distortion and prevent any one cylinder causing distortion of neighbouring cylinders. 单独的水套设计保证汽缸套变形低, 防止缸套受其它缸影响而变形。The liners must be a neat fit in the cylinder block to prevent distortion. 汽缸套必须要良好地安装在汽缸套上防止变形。For two stroke engines it is essential that the correct angular position is obtained, so exhaust and air inlet ports are aligned with their respective passages. 二冲程柴油机汽缸套要有正确的安装角度, 要使进排气口正好与它们各自的通道成一线。Sealing rings are still provided between the liner and the cylinder block, even though there may be no water jacket in the block, to prevent oil leaking into the cylinder block section. 即使汽缸体上没有水套, 在汽缸套和汽缸体之间也要有密封圈, 防止油漏泄到汽缸体内。Where the cylinder block provides a water jacket for the cylinder liner, sealing rings are required at the lower part of the liner. 这种情况下, 汽缸体就作为汽缸套的水套, 密封圈安装在汽缸套的下部。Some sealing arrangement is also needed in the liner above the jacket. 在衬套里也需要其它一些密封, It is usual to provide a telltale between the two lower sealing rings, so that water leaking past the upper seal ring or oil leaking past the lower ring may be readily detected. 它在两道较低密封环之间形成了一个指示器, 所以如果水从上面的密封环漏泄或者油从下面的密封环漏泄都可以容易地检测出来。An alternative to having a jacket around the upper part of the liner is to have a solid upper section liner of the desired thickness for

strength, and to provide some sort of cooling, usually bore cooling.一种替代方法是围绕汽缸套的上部设计水套,也就是钻孔冷却。缸套的上部较厚,提供足够的强度,也可以实现一些冷却。

CYLINDER HEAD 汽缸盖

The cylinder head must effectively close the upper part of the cylinder and provide space for air inlet and exhaust valves, a fuel injector and a number of other fittings such as air start valve, relief valve and indicator cock. 汽缸盖必须有效地封住汽缸的上部,为进排气阀、燃油喷射器,还其他一些装置如:空气启动阀、安全阀和示功考克等提供安装空间, In Vee type engines it is usual to fit air start valves to one bank of cylinders only. 在V型机上,通常只在一系列汽缸上安装启动空气阀。The head must resist mechanical stress due to peak firing pressure and must also be cooled to maintain strength. 汽缸盖必须能够承受爆发压力所产生的机械应力,必须冷却以保持强度。As with cylinder liners, cooling can present problems related to thermal stress and an effective system of coolant circulation is needed. 汽缸套的冷却可能存在热应力问题Although many cylinder heads still employ cored-out cooling spaces, some engines (e.g. Sulzer 'Z' range) make use of bore cooling systems. 尽管很多汽缸盖采用中空冷却腔冷却,但是一些柴油机(如:苏尔寿Z系列)采用钻孔冷却方式。In some cases combined bore and cavity cooling is used, with the bores located at the lower face closest to the combustion chamber where the cooling effect is critical. 一些时候,钻孔冷却和冷却腔冷却会混合应用,钻孔在汽缸盖的下表面紧靠燃烧室,这里的冷却效果很关键。This lower face is known as the 'flame plate'.下表面一般称作“底板” The cylinder head sits on the top of the liner and holds it in place. 汽缸盖位于汽缸套上面,并固定汽缸套A number of hydraulically tightened studs are usually employed to hold the head onto the cylinder block.一些液压上紧螺栓通常用来把汽缸盖固定到汽缸体上 Cooling water flows from the cylinder liner to the cylinder head either directly, with self sealing connections, or by means of connecting pipes. 汽缸套和汽缸盖之间密封连接或采用连接管后,冷却水直接从汽缸套流向汽缸盖Water outlet flow is from the top of the head to a common flow pipe. 冷却水从汽缸盖上部流出到一个公共管路。Some form of air vent arrangement is usually provided at the water outlet pipe to ensure removal of air from the coolant passageways following overhaul.在冷却水出口管通常安装一些除气装置,用以大修后从冷却管路中驱除气体。 For most engines each unit, cylinder liner jacket and head, can be isolated from the coolant circulating system so it is only necessary to drain the unit being overhauled. 对于大多数柴油机,汽缸套、水套和汽缸盖各单元都可以从冷却循环中独立出来,所以各单元大修时仅需要单独放空。The cylinder head also connects to the air inlet and exhaust trunkings, passageways are cast into the cylinder head to permit the flow of combustion air and exhaust gas.汽缸盖也连接到空气入口和排气管,这些通道铸造在汽缸盖上,允许新鲜空气流入废气排出。

Boiler Management 锅炉管理

General management principles and operating procedures are well known and must be always followed to avoid boiler mishaps. 应该熟知全部的管理原则和操作规程，必须按原则和程序操作，避免锅炉事故。

With many small package boilers, the automatic control sequence usually ensures that the boiler fire is initially ignited from a diesel oil supply, and changed over to the usual source when ignition is completed. 对于大多数小型锅炉，自动控制程序保证锅炉使用柴油点火，当点火完成时在转换成常用的燃料。With good management, to facilitate subsequent starting from cold, the fuel system of large boilers will have been flushed through with diesel oil when the boiler was

on light duty immediately prior to being secured. 管理良好的锅炉，为了方便下一次的起动，当大型锅炉在轻负荷马上要停止之前，会用柴油冲洗燃油系统。When burning such diesel fuel it is essential for safety that only the correct (small) burner tip should be used. 当燃烧这样的柴油时，要注意安全，只能使用正确的（小型的）喷油器。It should be kept in mind that if fire does not light, immediately shut off fuel and vent furnace. 要注意一旦点火不成功，应马上停止供油，给锅炉扫风。

Complete ignition of fuel in the furnace is essential. 完全点燃炉膛内的燃油是重要的。The burner flame, the smoke indicator and the funnel should be frequently observed. 应该经常观察燃烧的火焰、烟雾指示器和烟囱。With satisfactory combustion, the flame should appear incandescent with an orange shade at the flame tip, and a faint brownish haze should show at the funnel. 燃烧良好，火焰就会呈现出明亮色，火焰端部呈橙色，烟囱排烟呈淡褐色。If on first ignition the flame is uncertain, badly shaped and separates from the primary swirler, momentary opening or closing of air register may correct. 如果初次点火后火焰不稳定，形状不良并与旋流配风器分开，瞬间开闭风门会改善这种效果。

The pH value of the boiler feed water should be kept between 8 and 9 and the boiler density less than 300 ppm, but, if water samples show a heavy concentration of suspended mater, short blow-downs of 20 seconds duration should be given until the sludge content is seen to be reduced. 锅炉给水的 PH 值应该在 8-9 之间，且浓度小于 300ppm，但是如果水样显示悬浮物浓度过高，应进行 20 秒的下排污，直到看到脏物减少。The boiler should be blown down when the oil burner is operating, the water level lowered and then restored to prove the functioning of the low water cut-out and the oil burner start-up equipment. 下排污应该在燃烧器工作时进行，锅炉水位应降低然后恢复，以证明低水位切断功能和锅炉燃烧器启动装置正常。The boiler scum valve should also be operated at this time to keep the water level clear floating scum. 这时锅炉上排污阀也应该进行操作以保持水面没有浮渣。

批注 [s17]:

Fuel burner components and igniter electrodes should be cleaned weekly and the furnace examined to ensure that there are no excess carbon deposits. 燃烧器部件和点火电极应该每周清洁，炉膛每周检查以确定没有过量积碳。

Tubes in the exhaust gas section of the boiler should be brushed through at about six-monthly intervals, and those in the oil-burning section periodically examined and cleaned as necessary with a wire bristle brush. 锅炉废气区域的管子间隔六个月左彻底涮洗一次，使用燃油区域的管路应定期检查，必要的时候可以用钢丝刷清洗。With correct feed water treatment, blow-down procedures and sludge contents in water samples at a stable level, it should not be necessary to wash out the water side of the boiler more than once every three or four months. 锅炉给水处理好，排污操作正确，且水样中泥渣的含量稳定，则锅炉水侧每三四个月清洗一次就可以了。

Boiler fires may be out for long periods when a ship is at sea and the boiler steaming maintained by heat input from waste heat recovery plant. 当船舶在海上航行的时候，锅炉可长时间停火，可以由废热回收装置保持锅炉供气。This operation is free from hazard, but feed water and boiler water treatment must be maintained to prevent internal deterioration or scale formation. 这时运行锅炉没有危险，但是必须要处理给水和炉水，防止内部腐蚀或形成水垢。Water level controllers must be kept operable to protect external steam-using plant from water "carry-over" danger. 必须保持水位控制器正常工作，以防止外部用气装置受到蒸汽带水的危害。

If a boiler is isolated from the steam-using system it must be kept either in closed dry storage with a suitable internal desiccant, or completely full of treated water, or under a low steam

pressure preferably maintained by a steam-heated coil. 如果要将锅炉从蒸汽系统隔开, 或者在锅炉内部放适量的干燥剂使锅炉干燥密闭保养, 或者是装满处理过的水, 或者是用蒸汽盘管加热让锅炉维持在低气压下。

Regular testing of boiler protective devices must be implemented. 锅炉保护装置必须定时实验。

Frequent comparison of drum-mounted and remote-reading water level indicators: discrepancies between these have contributed to failures because of overheating through shortage of water, when a boiler was being oil-fired. 要经常比较锅炉上的水位计和远程水位计的读书, 当锅炉处于着火工作状态的时候, 它们之间的差异曾经导致过因缺水而过热的故障。If in doubt as to the true boiler water level, i.e. whether a water level indicator sightglass is completely full or empty, when a unit is being oil-fired the fire should be immediately extinguished until the true level is resolved. 如果对锅炉的真实水位有所怀疑, 也就是说, 无论水位计观察镜显示是全满的还是全空的, 当锅炉处于燃油工作状态时应立即熄火, 直到恢复真实水位。

Procedures should be predetermined and followed in the event of shortage of water, bulging or fracture of plates or furnace, or bursting of water tubes. 应该预先制定一些程序, 并在管板或炉膛变形、裂纹, 锅炉缺水或者水管爆裂的时候执行这些程序。In general, fires should be immediately extinguished by remote tripping of fuel supply valves; forced draught air pressure maintained if there is any risk of escaping steam entering the boiler room; stem pressure relieved if metallic fractures seem possible; and boiler water level maintained, where practicable, until the boiler begins to cool down. 通常情况下, 应立即通过燃油远控速闭阀使锅炉熄火; 如果蒸汽可能逸出进入锅炉间, 应该保持强制通风压力; 如果有可能发生金属破裂, 应释放蒸汽压力; 如果可能的话, 在锅炉冷却之前应保持锅炉的水位。

批注 [s18]: Steam

Regular operation of soot blowers, if there are fitted, when the boiler is on oil-fired operation. 如果装有吹灰器, 应在锅炉处于燃油工作时定期吹灰。The steam supply line must be thoroughly warmed and drained before the blowers are used, the air/fuel ratio increased throughout the action, and blowers greased after use. 使用吹灰器之前, 供气管路应完全预热、放残。使用期间应加大风油比, 使用之后应涂油脂。

Immediate investigation of any high salinity alarms in condensate system, and elimination of any salt water or oil contamination of boiler feed water system. 如果冷凝系统有高盐度报警应立即进行调查, 并清除给水系统的海水和油污。

Safety precautions taken before entering a boiler connected to another boiler under steam. 进入一个与工作锅炉相连的锅炉之前, 应采取安全预防措施。

The main engine may be kept in operation with the boiler dry and the gases passing through the exhaust gas section. 当锅炉无水时, 主机仍可以保持运转, 而使排烟通过锅炉的废气区域。If this is to be done for a prolonged period it is advisable to allow a current of air to flow through the boiler by removing manhole, sight hole and mudhole covers. 如果这种操作将在长时间内进行, 那么打开人孔、观察窗和泥渣孔盖板使空气流过锅炉是明智的。If refilling a hot boiler the main engine speed should be reduced to slow for half an hour and the feed water supplied be as hot as possible; thereafter the main engine may be brought up to power over a similar period. 如果要向热的锅炉内加水, 主机的转速应降低运行半小时, 给水应尽可能的热, 然后, 主机可在相同时间内恢复功率。

LESSON 19

Refrigeration System 制冷系统

Fundamentals 基本原理

Refrigeration is the process of removing heat, and the practical application is to produce or maintain temperatures below the ambient. The basic principles are those of thermodynamics. 制冷是移除热的过程, 实际应用就是产生或保持低于环境的温度。基本原理是热力学的一些知识。

Heat is one of the many forms of energy and mainly arises from chemical sources. 热是能量的一种形式, 主要来自于化学能。The heat of a body is its thermal or internal energy, and a change in this energy may show as a change of temperature or a change between the solid, liquid and gaseous states. 热是物体的热能或内能, 热能的改变可能会带来温度的改变或固态、液态和气态之间的变化。Matter may also have other forms of energy, potential or kinetic, depending on pressure, position and movement. 物质可能有其它形式的能量, 比如势能或动能, 这些主要取决于物质的压力、位置和运动。Enthalpy is the sum of its internal energy and flow work and is given by: $H = u + Pv$. 焓是物质的内能和流动功的总和, 可表达为 $H = u + Pv$ 。In the process where there is steady flow, the factor Pv will not change appreciably and the difference in enthalpy will be the quantity of heat gained or lost. 在稳定流动的过程中, Pv 项不会改变, 焓的变化就是得到或失去的热量。

If a change of enthalpy can be sensed as a change of temperature, it is called *sensible heat*. 如果焓的变化, 就能感觉到温度的变化, 就叫做显热。This is expressed as specific heat capacity, i.e. the change in enthalpy per degree of temperature change, in $\text{kJ}/(\text{kg K})$. 这表示为比热, 也就是温度每度的变化焓的变化量, 单位是 $\text{kJ}/(\text{kg K})$ 。If there is no change of temperature but a change of state (solid to liquid, liquid to gas, or vice versa) it is called *latent heat*. 如果没有温度的变化, 但是有物质状态的改变 (固体变成液体, 液体变成气体, 反过来也一样。), 这就叫做潜热。This is expressed as kJ/kg , but it varies with the boiling temperature, and so is usually qualified by this condition. 潜热表达为 kJ/kg , 但是它随着沸腾温度变化, 所以它通常也就限定在沸腾条件下。

The temperature at which a liquid boils is not constant, but varies with the pressure. 液体沸腾的温度不固定, 它随着压力变化。Thus, while the boiling point of water is commonly taken as 100°C , this is only true at a pressure of one standard atmosphere (1.013 bar) and, by varying the pressure, the boiling point can be changed. 因此, 当一般认为水的沸点是 100°C , 这只是水在一个标准大气压 (1.013 bar) 下的沸点, 当压力改变时, 沸点也改变。

The boiling point is limited by the *critical temperature* at the upper end, beyond which it cannot exist as a liquid, and by the triple point at the lower end, which is at the freezing temperature. 沸点限定在临界温度以上, 临界温度以下不存在液体, 临界点以下的三相点是凝固点。Between these two limits, if the liquid is at a pressure higher than its boiling pressure, it will remain a liquid and will be subcooled below the saturation condition, while if the temperature is higher than saturation, it will be a gas and superheated. 在这两个界限之间, 如果液体的压力比它的饱和压力高, 那么它保持液体状态, 在饱和状态以下有一定过冷, 如果温度比饱和温度高, 那么它就变成气体, 有一定过热。If both liquid and vapour are at rest in the same enclosure, and no other volatile substance is present, the condition must lie on the saturation line. 如果液体和气体同时存在于一个密闭容器如果没有其它不稳定物质存在, 这时必定是处于饱和状态。

Basic vapour compression cycle 基本蒸发压力循环

A liquid boils and condenses—the change between the liquid and gaseous states—at a

批注 [s19]: ?? 缺少单位质量, 是不是不应该用千焦

temperature which depends on its pressure, within the limits of its freezing point and critical temperature. 液体的蒸发和冷凝——在液体状态和气体状态之间变化——依赖于其压力，并且要处于凝固点和临界温度之间。In boiling it must obtain the latent heat of evaporation and in condensing the latent heat must be given up again. 在沸腾时，液体必须获得蒸发潜热，在冷凝时，潜热必须再释放出去。The basic refrigeration cycle makes use of the boiling and condensing of a working fluid at different temperatures and, therefore, at different pressures.基本的制冷循环利用工作流体在不同温度和不同压力下的蒸发和冷凝。

Heat is put into the fluid in the evaporator at the lower temperature and pressure and provides the latent heat to make it boil and change to a vapour. 在蒸发器中，压力比较低，饱和温度也比较低，这时热量传递给流体，也就是向流体提供潜热，使流体沸腾变成蒸汽。This vapour is then mechanically compressed by the compressor to a higher pressure and a corresponding saturation temperature at which its latent heat can be rejected in the condenser so that it changes back to a liquid.这些蒸汽被压缩机机械压缩成高压蒸汽，在冷凝器中，在对应的饱和温度下它的潜热被释放出来，所以蒸汽又变回液体。

A working system will require a connection between the condenser and the inlet to the evaporator to complete the circuit. 一个工作系统需要在冷凝器和蒸发器入口之间建立连接以完整整个回路。Since these are at different pressures this connection will require a pressure reducing and metering valve.由于它们的压力不同，所以这个连接环节需要一个具有降压和调整功能的阀。Since the reduction in pressure at this valve must cause a corresponding drop in temperature, some of the fluid will flash off into vapour to remove the energy for this cooling. 由于在该阀处有压降，必定会引起相应的温度降，一些流体闪发成蒸汽带走热量实现制冷。The volume of the working fluid therefore increases at the valve by this amount of flash gas, and gives rise to its name, the expansion valve.工作流体在该阀后由于闪发成气体所以体积增大，这也就得到它的名字，膨胀阀。

Refrigerants 制冷剂

Ideal properties for a refrigerant 制冷剂的理想性能

It will be useful to remind ourselves of the requirements for a fluid used as a refrigerant.这将帮助我们记住用来作为制冷剂的流体所应具备的条件。

- A high latent heat of vaporization 高的蒸发潜热
- A high density of suction gas 高的吸气密度
- Non-corrosive, non-toxic and non-flammable 无腐蚀性、无毒性、不易燃烧
- Critical temperature and triple point outside the working range 临界温度和三相点在工作温度范围以外。
- Compatibility with component materials and lubricating oil 与原件材料及润滑油相兼容
- Reasonable working pressures (not too high, or below atmospheric pressure) 合适的工作压力（不太高，也不低于大气压力）
- High dielectric strength (for compressors with integral motors) 高绝缘强度（压缩机和电机做成一体）
- Low cost 低成本
- Ease of leak detection 漏泄检查容易
- Environmentally friendly 环境友好

Ozone depletion potential (ODP) 臭氧消耗潜能值

The ozone layer in our upper atmosphere provides a filter for ultraviolet radiation, which can be harmful to our health. 臭氧层位于大气层的外面，提供了一个防止紫外线辐射的滤光器，

紫外线对人们的健康有害。Research has found that the ozone layer is thinning, due to emissions into the atmosphere of chlorofluorocarbons (CFCs), halons and bromides. 研究发现由于向大气中排放氯氟烃(CFCs), 哈龙以及溴化物, 臭氧层正在变薄。The Montreal Protocol in 1987 agreed that the production of these chemicals would be phased out by 1995 and alternative fluids developed. 1987年的蒙特利尔协议同意这些化学产品到1995之前逐渐淘汰, 开发替代产品。

- R22 is an HCFC and now regarded as a transitional refrigerant, in that it will be completely phased out of production by 2030, as agreed under the Montreal Protocol. R22是一种氢代氯氟烃, 现在被认为是一种过渡制冷剂, 根据蒙特利尔协议, 它到2030年之前要完全被淘汰,

Global warming potential (GWP) 全球变暖潜能

Global warming is the increasing of the world's temperatures, which results in melting of the polar ice caps and rising sea levels. 全球变暖就是世界温度是升高, 它导致两极冰帽融化, 海平面升高。It is caused by the release into the atmosphere of so-called 'greenhouse' gases, which form a blanket and reflect heat back to the earth's surface, or hold heat in the atmosphere. 这时由于所谓“温室气体”释放到大气中所引起的, 温室气体就像毯子一样包在地球外层, 把热反射回地球表面或把热保留在大气层里。The most infamous greenhouse gas is carbon dioxide (CO₂), which once released remains in the atmosphere for 500 years, so there is a constant build-up as time progresses. 最声名狼藉的温室气体是二氧化碳 (CO₂), 它一旦释放到空气中, 会在大气中存在500年, 所以随着时间的发展, 它的含量会不断升高。

The main cause of CO₂ emission is in the generation of electricity at power stations. 二氧化碳主要是由发电厂发电所释放的。Each kWh of electricity used in the UK produces about 0.53 kg of CO₂ and it is estimated that refrigeration compressors in the UK consume 12.5 billion kWh per year. 在英国每用一度电就会产生大约0.53 kg 的二氧化碳, 据估计在英国制冷压缩机每年会消耗12.5亿度电。The newly developed refrigerant gases also have a global warming potential if released into the atmosphere. 新开发的制冷剂气体如果释放到大气中, 也有全球变暖的潜能, For example, R134a has a GWP of 1300, which means that the emission of 1 kg of R134a is equivalent to 1300 kg of CO₂. 例如R134a的全球变暖潜能值为1300, 也就意味着释放1kg的R134a就相当于释放1300kg的CO₂。

Ammonia and the hydrocarbons 氨和碳氢化合物

These fluids have virtually zero ODP and zero GWP when released into the atmosphere. 这些液体释放到大气中, 实际上没有臭氧消耗潜能值和全球变暖潜能值。Ammonia has long been used as a refrigerant for industrial applications. 氨已经作为工业用制冷剂很长时间。The engineering and servicing requirements are well established to deal with its high toxicity and flammability. 已经很好地满足了工程上和服务上的要求来处理它的高毒性和可燃性。Ammonia cannot be used with copper or copper alloys, so refrigerant piping and components have to be steel or aluminium. 氨不能和铜及铜合金一起使用, 所以制冷管系和部件必须是钢或铝。One property that is unique to ammonia compared to all other refrigerants is that it is less dense than air, so a leakage of ammonia results in it rising above the plant room and into the atmosphere. 氨独有的一个特性是与其它所有的制冷剂相比, 它的密度比空气轻, 所以氨的漏泄会导致氨上升到机械处所的上部, 最后飘散到大气中。If the plant room is outside or on the roof of a building, the escaping ammonia will drift away from the refrigeration plant. 如果机械处所在外面或在整个建筑物的顶部, 从制冷系统中漏泄出来的氨会慢慢散去。The safety aspects of ammonia plants are well documented and there is reason to expect an increase in the use of ammonia as a refrigerant. 如果能证明氨制冷装置安全方面没有问题的话, 那么就有理由相信

以氨作为制冷剂就会增多。

Hydrocarbons such as propane and butane are being successfully used as replacement and new refrigerants for R12 systems. 碳氢化合物比如丙烷和丁烷成功的替代并作为R12系统的新制冷剂。They obviously have flammable characteristics which have to be taken into account by health and safety requirements. 它们明显的具有可燃性，必须考虑健康与安全方面的一些要求。However, there is a market for their use in sealed refrigerant systems such as domestic refrigeration and unitary air-conditioners.然而，在密封式制冷系统中（比如家用制冷设备和单体式空调）具有应用市场。

Refrigerant blends 混合制冷剂

Many of the new, alternative refrigerants are 'blends', which have two or three components, developed for existing and new plants as comparable alternatives to the refrigerants being replaced. 一些新的、可供选择的制冷剂混合在一起，它具有两种或三种成分，作为被替代冷剂的相似制冷剂，可供现有的和新的装置使用，They are 'zeotropes' with varying evaporating or condensing temperatures in the latent heat of vaporization phase, referred to as the 'temperature glide'. 它们是非共沸混合物，在蒸发阶段发生潜热时，具有不同的蒸发或冷凝温度，就叫做“温度滑移”。

The temperature glide can be used to advantage in improving plant performance, by correct design of the heat exchangers. 通过合理设计热交换器，可以有效利用温度滑移来提高装置性能。A problem associated with blends is that refrigerant leakage results in a change in the component concentration of the refrigerant. 一个和混合冷剂相关的问题是如果制冷剂漏泄会导致制冷剂成分浓度的变化。However, tests indicate that small changes in concentration (say less than 10%) have a negligible effect on plant performance.可是，测试显示浓度的变化不大时（变化小于10%），对装置的性能的影响可以忽略不计。

The following recommendations apply to the use of blends:下面是使用混合冷剂的建议：

- The plant must always be charged with liquid refrigerant, or the component concentrations will shift.装置必须加装液体冷剂，否则冷剂成分浓度会发生改变。
- Since most blends contain at least one flammable component, the entry of air into the system must be avoided.由于大多数混合冷剂至少有一种可燃成分，所以必须避免空气进入系统。
- Blends which have a large temperature glide, greater than 5K, should not be used for flooded-type evaporators.混合冷剂有大的温度滑移，甚至超过5K，所以不应在液流式蒸发器中使用。