目录

1 引言

1.1 清洗建筑表面的意义

随着人类社会的不断发展进步，城市规模不断扩大，城市建筑更加规范，完美。千姿百态的各式建筑，尤其是高层建筑外墙都用各种建筑材料进行装饰，如粘帖各色墙砖，瓷砖，马赛克，或涂上涂料，但是，自然界的风吹雨打，日光辐射，尘埃污染，以及一些人为或偶然事故等原因，一段时间过后，建筑表面都将不同程度地变得污浊灰暗，破旧不堪，在环境差的地区，污染或损坏还相当严重。建筑表面就像人身上的外衣，要保持清洁，就需要经常清洗，整理。为此，世界发达国家和地区，对保持建筑表面的清洁非常重视，并以法律的形式明确规定，每年必须定期清洗，否则将受到处罚。近年来，我国各级政府部门的环境保护意识已发生了很大改变，国内一些大，中城市，特别是旅游，开放城市，旅游景点，为保持建筑表面清洁，也制定出台了相应的法规，全国范围的卫生评比活动，把保持建筑表面清洁列为考核的重要指标之一，其中高层建筑的外墙，醒目，突出，自然也就成为检查的重中之重。

有信息表明，十·五期间国家用于环境保护的投资将由九·五期间国民生产总值的1.5%翻倍增加至4%，同时还伴随以产业政策的优惠。所以，随着我国改革开放的不断深入，政府，公民的环保意识的不断加强，建筑表面清洁问题必将引起各方面的高度重视，建筑清洗行业必然具有广泛的发展前景，将产生巨大的经济效益和社会效益.
建筑表面清洗主要包括外墙清洗和中央空调风管的清洗，目前外墙清洗是采用传统的“蜘蛛人”清洗，这是以牺牲生命为代价的非人工作，部分城市颁布了建筑表面清洗条例； 由于非典事件，公共卫生得到了高度的重视，特别是中央空调风管的清洗，最近有关中央空调的清洗条例很快出台；因此对于建筑表面清洗提供一个完备的解决方案，必然打破一个传统的产业格局，改变了人们的工作方式，用机器人清洗代替传统的人工清洗或无法清洗，是必然的发展趋势。

1.2 目的和现实意义

洗墙机的功能主要在于清洗大楼窗户、外墙等外部结构，然而碍于在清洗大楼时清洗后废水的处理，清洗的效果、效率等等，目前市面上尚无自动的大楼洗墙机。

改革开放以来，随着我国经济的高速发展，高层式建筑如雨后春笋般的拔地而起。高楼外墙的外观保养和清洁成为楼宇管理不可缺少的一部份。有需求就由市场，高楼外墙的清洁必将成为一种经济效益高，前景广阔的行业。在中国，这种行业正在逐渐兴趣。我国高墙清洁主要采取两种形式。

1.3 研究现状

综观目前市面上可见的洗墙机，清洗方式主要还是以人工清洗为主，所以都是以挂笼垂降，再以人工方式清洗墙面；然而垂挂以及挂笼的升降方式便较具变化。传统的是人手清洁，用绳把人系住和定位，逐层清洁。这种方式人在半空吊来吊去的（好象攀崖运动员下山时那样），劳动强度高，效率低，因为主体是人，所以带有一定的危险性。

现代的机器人清洁，现代科技的发展，机器人代替人手工作是必然的趋势，在国外和我国的一些清洁公司已经采用了机器人来进行高楼外墙的清洁工作，但是这些机器人构造复杂，操作复杂，功能繁多（有些功能是很少用到或在某些场合不会用到），造成成本高（如果是一些由人工智能的机器人就更加不用说了）和资源浪费的现象。针对这个问题，我们设计了一个操作简单，经济实用的高楼外墙清洁机器。

2 方案评价与选择

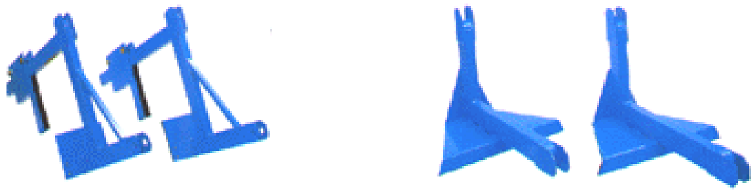
2.1 高楼外墙清洁机的结构和工作

现代高楼外墙自动清洗机的结构主要分为下面几种:

2.1.1 设置于顶楼的支撑突梁

以下为一些常见的支撑突梁：

（1）固定式如图 2.1 所示：



（A）F 型突梁　　（B）L 型突梁

图 2.1 固定式突梁

(2)活动式：

设有活动滑轨,如图 2.2 为一种滑轨：

图 2.2 滑轨

滑轨式的作动情形如图 2.3 所示：

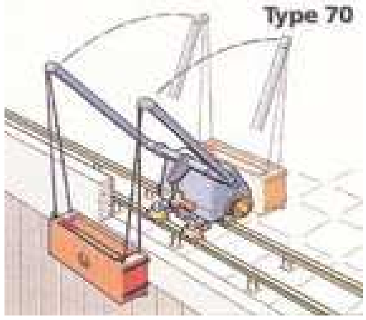
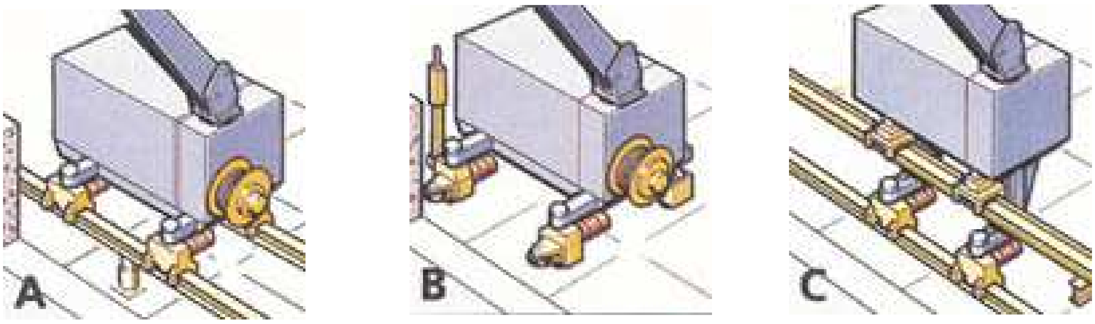


图 2.3 滑轨式的作动情形

滑轨有多种形式如图 2.4 所示：



A.水平式滑轨　　B.自走平台　　C.垂直式滑轨

图 2.4 多种形式的滑轨

直接将大型起降车设置于顶楼，方便随时清洗，亦有助施工维修，但成本高昂且占空间。

2.1.2 支撑缆绳

缆绳能承受高度张力，目前专用缆绳就可达到需求。

2.1.3 乘载用挂笼

小型挂笼如图 2.5 所示：

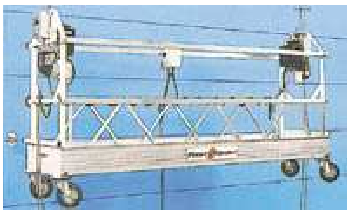


图 2.5 小型挂笼

中型挂笼如图 2.6 所示：

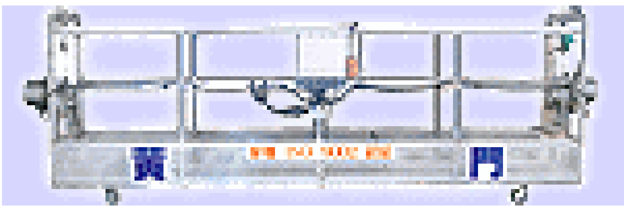


图 2.6 中型挂笼

2.1.4 动作马达

对于马达，一般来说有以下要求：

A. 高扭力、低转速。

B.断电自动煞车。

C.机械煞车装置。

D.静定功能。

2.1.5 升降结构

对于升降的结构，目前计划主要依现有一般市面上可见的机构加以改良，作为自动洗墙机的作动装置，装在楼顶的步进电动机带动卷桶控制钢丝绳的收放，使的刷子部分的执行机构能在高墙上纵向移动。在这里,选择卷扬机类似的机构,加以改进。

2.1.6 清洗刷

考虑到刷子受到的摩擦力很小 ，刷子的转动动力由小电机提供，如图所示
刷子部分采用红外线测距。当墙上的玻璃窗等与墙的竖直距离不等时，刷子不能很好的清洗玻璃等凹或凸出来的部分。所以从机器采用红外线测距， 使刷子能更好的工作，即使有突出的墙沿，也可以通过机器自己调节(线圈产生的磁场和弹簧力来调节)
刷子由一个独立的电动机带动。

为了使机器在刷子往返运动中，不会使机构左右摇摆，所以采用一些辅助机构来减少左右摇摆，如图所示，采用末端加有一个轮，此轮与墙接触。当机器向下运动时，轮与墙之间是滚动摩擦，使机器向下运动时，可以使机器与墙之间保持一定的距离，从而不会撞到墙或者玻璃，当墙左右摇晃时，这时，轮与墙之间产生滑动摩擦，对机器左右摇摆有一定的抑制作用。

还有一些辅助机构使得清洁机在墙上工作更加平稳。

2.2 方案评价与选择

根据任务书的要求，结构简单，操作方便，投资小，成本低，安全可靠，工作效率高，故选用，水平式滑轨，支撑缆绳，小型挂笼，升降机构采用类似卷扬机机构，工作部，利用工作电动，经减速器减速，带动清洗刷转动，实现清洗功能。

3 运动学及结构方案的确定

根据任务书要求，一小时可以清洗墙面 600-800 平方米，考虑到结构简单，直接单向进给，故只考虑升降，而且要达到 600-800 平方米，所以要选用大型号的清洗刷。其结构如图 3.1 所示：

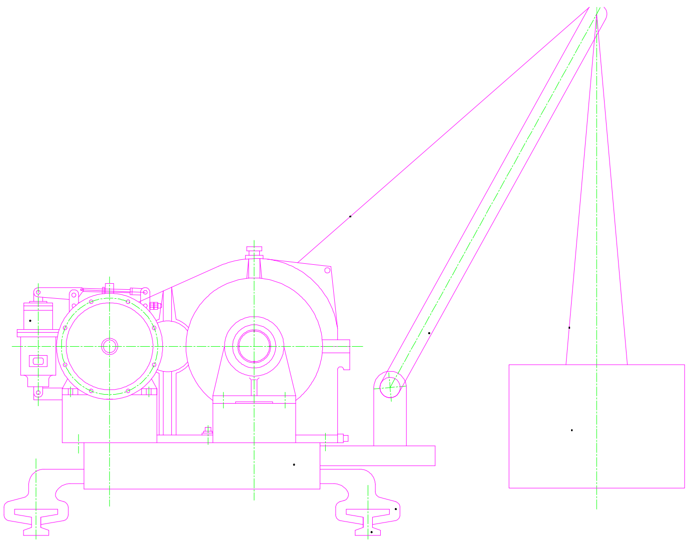


图 3.1 清洗刷结构图

3.1 运动学参数选定

初选卷扬机，根据 GB/T 1995-2002，选用双卷快速快溜放卷扬机，额定速度为 20m/min-25min，额定载荷为 25KN。

根据初选的卷扬机，则定清洗刷直径应 500mm。

清洗刷与墙面的摩擦力

查机械设计手册得工程塑料的动摩擦因数在$u_k = 0.1 \sim 0.5$之间，因为，清洗刷基本上靠自动压在墙面上，又要考虑到清洗干净，故选用动摩擦因数较大的工程塑料，选定其动摩擦因数为$u_k = 0.5$，估算清洗装置$200 \sim 300kg$，故

$$F = Nu_k = 2000N \times 0.5 = 1000N$$

工作机所需输入功率：

$$P_w = \frac{Fv}{1000\eta_w} = \frac{1000 \times 2.3}{1000 \times 1} = 2.30KW$$

各部件的传动效率：

工作机的效率：$\eta_w = 1$

传动装置中各部分的效率, 查机械手册得

8 级精度的一般齿轮传动效率：$\eta_{齿} = 0.97$

弹性联轴器传动效率：$\eta_l = 0.992$

齿式联轴器传动效率：$\eta_\lambda = 0.99$

球轴承传动效率：$\eta_{球} = 0.99$(一对)

滚子轴承：$\eta_{滚} = 0.99$(一对)

电动机至工作机之间传动装置的总效率：

$$\eta = \eta_l \eta_{球} \eta_{齿} \eta_{滚} \eta_{齿} \eta_{滚} \eta_\lambda$$
$$= 0.992 \times 0.99 \times 0.97 \times 0.98 \times 0.97 \times 0.98 \times 0.99 = 0.879$$

所需电动机功率

$$P_d = \frac{P_w}{\eta} = \frac{2.30}{0.879} = 2.617KW$$

由

$$v = \frac{\pi D n_w}{60 \times 1000}, 得\ n_w = \frac{60 \times 1000 v}{\pi D} = \frac{60 \times 1000 \times 2.30}{\pi \times 500} = 87.5 r/\min$$

查表 13-2,得圆柱齿轮传动单级传动比常值为 3～5,故电动机转速的可选范围:

$$n = (i_1 i_2) n_w = (3^2 \sim 5^2) \times 87.535 = 787.817 \sim 2188.38 r/\min$$

对 Y 系列电动机通常多选用同步转速为 1000r/min 或 1500r/min 的电动机,故选用同步转速为 1500r/min。

选用 Y100L2-4,额定功率 3KW,满载转速 1430r/min,电动机极数为 4，轴伸尺寸 $28^{+0.009}_{-0.004} \times 60$ 。其具体参数如下：

型号:　　Y100L2-4

额定功率/kW:　　3.0

铁心长度/mm:　　135

气隙长度/mm:　　0.3

定子外径/mm:　　155

定子内径/mm:　　98

定子线规 nc-dc:　　1-1.18

每槽线数:　　31

并联支路数:　　1

绕组型式:　　单层交叉

节距:　　　　　　1～9/2～10/18～11

槽数 Z1/Z2:　　　　36/32

转动惯量/(kg·m^2): 0.0067

质量/kg:　　　　　38

3.2 计算总传动比和分配各级传动比

传动装置的总传动比要求为

$$i=\frac{n_m}{n_w}=\frac{1430}{87.535}=16.336$$

式中： n_m —电动机满载转速,r/min.

一般推荐展开式二级圆柱齿轮减速器高速级传动比 $i_1=(1.3\sim1.5)i_2$, 取 $i_1=4.782, i_2=3.416$ 。

3.3 计算传动装置运动和动力参数

该传动装置从电动机到工作机有三轴,依次为Ⅰ、Ⅱ、Ⅲ轴,则:

3.3.1 各轴转速

$$n_1=n_m=1430\,r/\min$$

$$n_{II}=\frac{n_I}{i_1}=\frac{1430}{4.782}=299.038\,r/\min$$

$$n_{III}=\frac{n_{II}}{i_2}=\frac{n_m}{i_1 i_2}\frac{1430}{16.336}=87.537\,r/\min$$

式中: n_m —为电动机满载转速,r/min;

n_1、n_{II}、n_{III} —分别为Ⅰ、Ⅱ、Ⅲ轴转速,r/min;Ⅰ为高速轴,Ⅲ为低速轴.

3.3.2 各轴功率

$$P_I=P_d\eta_l=2.753\times0.992=2.731KW$$

$$P_{II}=P_I\eta_{齿}\eta_{球}=P_d\eta_l\eta_{齿}\eta_{球}=2.753\times0.992\times0.97\times0.99=2.623KW$$

$$P_{III}=P_{II}\eta_{齿}\eta_{滚}=P_d\eta_l\eta_{齿}\eta_{球}\eta_{齿}\eta_{滚}=2.753\times0.992\times0.97\times0.99\times0.97\times0.98=2.493KW$$

式中: P_d —为电动机输出功率,KW;

P_I、P_{II}、P_{III} —分别为Ⅰ、Ⅱ、Ⅲ轴输入功率,KW;

3.3.3 各轴转矩

$$T_I=9.55\times10^6\,P_I/n_I=9.55\times10^6\times2.731/1430=18238.50N\cdot mm$$

$$T_{II} = 9.55\times10^6\, P_{II}/n_{II} = 9.55\times10^6\times2.623/299.038 = 83767.45N\cdot mm$$

$$T_{III} = 9.55\times10^6\, P_{III}/n_{III} = 9.55\times10^6\times2.493/87.537 = 271978.14N\cdot mm$$

4 传动零件的设计计算

4.1 第一级齿轮传动设计计算

因传动无严格限制,生产批量小,故小齿轮用 40Cr,调质处理,硬度 241HB～286HB,平均取为 260HB;大齿轮用 45 钢,调质处理,硬度为 229HB～286HB,平均取为 240HB.齿轮采用非对称支承结构安装。计算步骤如下:

齿面接触强度计算

4.1.1 初步计算

转矩 T_1 ，$T_1 = 18238.50N \cdot mm$

齿宽系数 Ψ_d ，由表 12.13,取 $\Psi_d = 1.0$

A_d 值,由表 12.16,估计 $\beta \approx 13°$，取 $A_d = 88$

接触疲劳极限 $\sigma_{H\lim}$，由图 12.17c,得

$\sigma_{H\lim 1} = 710MPa, \sigma_{H\lim 2} = 580MPa$

初步计算的许用接触应力 $[\sigma_H]$:

$[\sigma_{H1}] \approx 0.9\sigma_{H\lim 1} = 0.9\times 710 = 639MPa$ $[\sigma_{H2}] \approx 0.9\sigma_{H\lim 2} = 0.9\times 580 = 522MPa$

传动比 i，$i(=u) = 4.782$

初步计算小齿轮直径 d_1 ，$d_1 \geq A_d \sqrt[3]{\frac{T_1}{\psi_d[\sigma_H]^2}\cdot\frac{u+1}{u}} = 38.1mm$，取 $d_1 = 45$

初步齿宽 b ，$b = \psi_d \cdot d_1 = 1.0\times 45 = 45mm$

4.1.2 校核计算

圆周速度 v，$v = \frac{\pi d_1 n_1}{60\times 1000} = \frac{\pi\times 45\times 1430}{60\times 1000} = 3.37\, m/s$

精度等级　由表 12.6，选用 8 级

齿数 Z_1、模数 m 和螺旋角 β:

$Z_1 = 22, Z_2 = iZ_1 = 105.24$，取 Z_2=105

$m_t = \frac{d_1}{Z_1} = \frac{45}{22} = 2.045455$，由表 12.3,取 $m_n = 2mm$

$$\beta=\arccos\frac{m_n}{m_t}=\arccos\frac{2}{2.045455}=12°6'5''$$（和估计值接近）

使用系数 K_A 由表 12.9,，$K_A=1.25$

动载系数 K_v, 由图 12.9, $K_V=1.18$

齿间载荷分配系数 $K_{h\alpha}$

$$F_t=\frac{2T_1}{d_1}=\frac{2\times18238.50}{45}=810.6N$$

$$\frac{K_AF_t}{b}=\frac{1.25\times810.6}{45}=22.52<100N/mm$$

$$\varepsilon_\alpha=\left[1.88-3.2\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right)\right]\cos\beta$$

$$=\left[1.88-3.2\left(\frac{1}{22}+\frac{1}{105}\right)\right]\cos12°6'5''=1.67$$

$$\varepsilon_\beta=\frac{b\sin\beta}{\pi m_n}=\frac{\psi_d\times Z_1}{\pi}\tan\beta=\frac{1.0\times22}{\pi}\tan12°6'5''=1.50$$

$$\varepsilon_\gamma=\varepsilon_\alpha+\varepsilon_\beta=3.17$$

$$\alpha_t=\arctan\frac{\tan\alpha_n}{\cos\beta}=\arctan\frac{\tan20°}{\cos12°6'5''}=20°25'2''$$

$$\cos\beta_b=\cos\beta\cos\alpha_n/\cos\alpha_t=0.98$$

由此得 $K_{H\alpha}=K_{F\alpha}=\varepsilon_\alpha/\cos^2\beta_b=1.67/0.98^2=1.74$

齿向载荷分布系数 $K_{H\beta}$, 由表 12.11,

$$K_{H\beta}=A+B\left[1+0.6(\frac{b}{d_1})^2\right](\frac{b}{d1})^2+C\times10^{-3}b$$

$$=1.17+0.16\left[1+0.6\times1^2\right]\times1^2+0.61\times10^{-3}\times45=1.453$$

载荷系数 K，$K=K_AK_VK_{H\alpha}K_{H\beta}=1.25\times1.18\times1.74\times1.453=3.73$

弹性系数 Z_E，由表 12.12, $Z_E=189.8\sqrt{MPa}$

节点区域系数 Z_H，由图 12.16, $Z_H=2.45$

重合度系数 $Z\varepsilon$ ，由式 12.31, 因 $\varepsilon_\beta>1$, 取 $\varepsilon_\beta=1$ 故

$$Z\varepsilon=\sqrt{\frac{1}{\varepsilon_\alpha}}=\sqrt{\frac{1}{1.67}}=0.77$$

螺旋角系数 Z_β，$Z_\beta=\sqrt{\cos\beta}=\sqrt{\cos 12°6'5''}=0.99$

接触最小安全系数 $S_{H\min}$，由表 12.14，得 $S_{H\min}=1.05$（一般可靠）

总工作时间 t_h，$t_h=4\times250\times16=16000h$

应力循环次数 N_L：

$$N_{L1}=60\gamma n_1 t_h=60\times1\times1430\times16000=1.3728\times10^9$$

$$N_{L2}=N_{L1}/i_1=1.3728\times10^9/4.782=2.8708\times10^8$$

接触寿命系数 Z_N，由图 12.18，$Z_{N1}=0.97$，$Z_{N2}=1.15$

许用接触应力 $[\sigma_H]$：

$$[\sigma_{H1}]=\frac{\sigma_{H\lim1}Z_{N1}}{S_{H\lim}}=\frac{710\times0.97}{1.05}=655.90MPa$$

$$[\sigma_{H2}]=\frac{\sigma_{H\lim2}Z_{N2}}{S_{H\lim}}=\frac{580\times1.15}{1.05}=635.24MPa$$

验算

$$\sigma_H=Z_EZ_HZ\varepsilon Z_\beta\sqrt{\frac{2KT_1}{bd_1^2}\cdot\frac{u+1}{u}}$$

$$=189.8\times2.45\times0.77\times0.99\times\sqrt{\frac{2\times3.37\times18238.50}{45\times45^2}\cdot\frac{4.782+1}{4.782}}$$

$$=478.81Mpa<[\sigma_{H2}]$$

计算结果表明，接触疲劳强度较为合适，齿轮尺寸无须调整。

4.1.3 确定传动主要尺寸

中心距 a $\quad a=\frac{d_1(i+1)}{2}=\frac{45\times(4.782+1)}{2}=130.095mm$

实际分度圆直径 $d_1=45.000mm$，$d_2=i_1d_1=4.782\times45=215.190mm$

齿宽 b，$b=\psi d_1=1.0\times45=45mm$，取 $b_1=55mm$，$b_2=45mm$

齿根弯曲疲劳强度验算

齿形系数$Y_{F\alpha}$: $Z_{V1}=\frac{Z_1}{\cos^3\beta}=\frac{22}{\cos^3 12°6'5''}=23$

$$Z_{V2}=\frac{Z_2}{\cos^3\beta}=\frac{105}{\cos^3 12°6'5''}=112$$

由图 12.21， $Y_{F\alpha1}=2.67$, $Y_{F\alpha2}=2.18$

应力修正系数$Y_{S\alpha}$ ，由图 12.22, $Y_{S\alpha1}=1.58$, $Y_{S\alpha2}=1.82$

重合度系数$Y\varepsilon$ ， $\varepsilon_{\alpha V}=\left[1.88-3.2(\frac{1}{Z_{V1}}+\frac{1}{Z_{V2}})\right]\cos\beta$

$$=\left[1.88-3.2(\frac{1}{23}+\frac{1}{112})\right]\cos 12°6'5''=1.67$$

$$Y\varepsilon=0.25+\frac{0.75}{\varepsilon_{\alpha V}}=0.25+\frac{0.75}{1.67}=0.70$$

螺旋角系数Y_β , $Y_{\beta\min}=1-0.25\varepsilon_\beta=1-0.25\times1=0.75$

（当$\varepsilon_\beta\geq1$时,按$\varepsilon_\beta=1$计算.）

$$Y_\beta=1-\varepsilon_\beta\frac{\beta}{120°}=1-1\times\frac{12.1°}{120°}=0.9>Y_{\beta\min}\text{, 故}Y_\beta=0.9$$

齿间载荷分配系数$K_{F\alpha}$ ， $\frac{\varepsilon_r}{\varepsilon_\alpha Y_\varepsilon}=\frac{3.17}{1.67\times0.70}=2.7$

前已求得$K_{F\alpha}=1.74<\frac{\varepsilon_r}{\varepsilon_\alpha Y_\varepsilon}$, 故$K_{F\alpha}=1.74$

齿向载荷分配系数$K_{F\beta}$ ，由图 12.14， $\frac{b}{h}=\frac{45}{2.25\times2}=10$, $K_{F\beta}=1.41$

载荷系数K , $K=K_AK_VK_{F\alpha}K_{F\beta}=1.25\times1.18\times1.74\times1.41=3.62$

弯曲疲劳极限$\sigma_{F\lim}$, 由图 12.23c, $\sigma_{F\lim1}=600MPa$, $\sigma_{F\lim2}=450MPa$

弯曲最小安全系数, 由表 12.14， $S_{F\min}=1.25$

应力循环次数N_L ， $N_{L1}=60\gamma n_1t_h=60\times1\times1430\times16000=1.3728\times10^9$

$$N_{L2}=N_{L1}/i_1=1.3728\times10^9/4.782=2.8708\times10^8$$

弯曲寿命系数Y_N , 由图 12.24， $Y_{N1}=0.9$, $Y_{N2}=0.98$

尺寸系数Y_X , 由图 12.25， $Y_X=1.0$

许用弯曲应力$[\sigma_F]$

$$\left[\sigma_{F1}\right]=\frac{\sigma_{F\lim1}Y_{N1}Y_X}{S_{F\min}}=\frac{600\times0.89\times1}{1.25}=427.20MPa$$

$$\left[\sigma_{F2}\right]=\frac{\sigma_{F\lim2}Y_{N2}Y_X}{S_{F\min}}=\frac{450\times0.94\times1}{1.25}=338.4MPa$$

验算

$$\sigma_{F1}=\frac{2KT_1}{bd_1m_n}Y_{F\alpha1}Y_{S\alpha1}Y_{\varepsilon}Y_{\beta}$$

$$=\frac{2\times3.62\times18238.50}{45\times45\times2}\times2.67\times1.52\times0.70\times0.9=83.36MPa<\left[\sigma_{F1}\right]$$

$$\sigma_{F2}=\sigma_{F1}\frac{Y_{F\alpha2}Y_{S\alpha2}}{Y_{F\alpha1}Y_{S\alpha1}}=83.36\times\frac{2.18\times1.82}{2.67\times1.58}=78.40<\left[\sigma_{F2}\right]$$

传动无严重过载,故不做静强度校核。

4.2 第二级齿轮传动设计计算

因传动无严格限制,生产批量小,故小齿轮用40Cr,调质处理,硬度取为280HB;大齿轮用45钢,调质处理,硬度取为260HB。齿轮采用非对称支承结构.计算步骤如下:

齿面接触强度计算

4.2.1 初步计算

转矩 T_2 , $T_2=83767.45N\cdot mm$

齿宽系数 Ψ_d ,由表 12.13,取 $\Psi_d=1.0$

A_d 值,由表 12.16,估计 $\beta\approx13°$,取 $A_d=88$

接触疲劳极限 $\sigma_{H\lim}$,由图 12.17c,得

$$\sigma_{H\lim1}=710MPa,\sigma_{H\lim2}=580MPa$$

初步计算的许用接触应力:

$$\left[\sigma_{H1}\right]\approx0.9\sigma_{H\lim1}=0.9\times710=639MPa\quad\left[\sigma_{H2}\right]\approx0.9\sigma_{H\lim2}=0.9\times580=522MPa$$

传动比 i, $i(=u)=3.416$

初步计算小齿轮直径 d_1 , $d_1\geq A_d\sqrt[3]{\frac{T_2}{\psi_d\left[\sigma_H\right]^2}\bullet\frac{u+1}{u}}=64.70$

初步齿宽 b , $b=\psi_d\bullet d_1=1.0\times72=72mm$

4.2.2 校核计算

圆周速度 v, $v=\frac{\pi d_1n_2}{60\times1000}=\frac{\pi\times72\times299.038}{60\times1000}=1.13m/s$

精度等级 选用 8 级

齿数、模数和螺旋角:

$Z_1 = 28, Z_2 = iZ_1 = 3.416\times 28 = 95.648,取Z_2 = 96$

$m_t = \frac{d_1}{Z_1} = \frac{72}{28} = 2.571492$, 由表 12.3, 取 $m_n = 2.5$

$\beta = \arccos\frac{m_n}{m_t} = \arccos\frac{2.5}{2.571492} = 13°32'10''$（和估计值接近）

使用系数 KA ，表 12.9,， $K_A = 1.25$

动载系数, 由图 12.9， $K_V = 1.10$

齿间载荷分配系数 $K_{h\alpha}$

$F_t = \frac{2T_2}{d_1} = \frac{2\times 83767.45}{72} = 2326.87N$

$\frac{K_A F_t}{b} = \frac{1.25\times 2326.87}{72} = 40.40 < 100N/mm$

$$\varepsilon_\alpha = \left[1.88 - 3.2\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)\right]\cos\beta$$

$$= \left[1.88 - 3.2\left(\frac{1}{28} + \frac{1}{96}\right)\right]\cos 13°32'10'' = 1.68$$

$$\varepsilon_\beta = \frac{b\sin\beta}{\pi m_n} = \frac{\psi_d \times Z_1}{\pi}\tan\beta = \frac{1.0\times 28}{\pi}\tan 13°32'10'' = 2.15$$

$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta = 1.68 + 2.15 = 3.83$

$$\alpha_t = \arctan\frac{\tan\alpha_n}{\cos\beta} = \arctan\frac{\tan 20°}{\cos 13°32'10''} = 20°31'27''$$

$$\cos\beta_b = \cos\beta\cos\alpha_n / \cos\alpha_t$$
$$= \cos 13°32'10''\cos 20 / \cos 20°31'27'' = 0.98$$

由此得 $K_{H\alpha} = K_{F\alpha} = \varepsilon_\alpha / \cos^2\beta_b = 1.68/0.98^2 = 1.75$

齿向载荷分布系数 $K_{H\beta}$, 由表 12.11,

$$K_{H\beta} = A + B\left[1 + 0.6(\frac{b}{d_1})^2\right](\frac{b}{d1})^2 + C\times 10^{-3}b$$
$$= 1.17 + 0.16\left[1 + 0.6\times 1^2\right]\times 1^2 + 0.61\times 10^{-3}\times 72 = 1.47$$

载荷系数 K, $K = K_A K_V K_{H\alpha} K_{H\beta} = 1.25\times 1.10\times 1.75\times 1.47 = 3.54$

弹性系数 Z_E, 由表 12.12， $Z_E = 189.8\sqrt{MPa}$

节点区域系数 Z_H, 由图 12.16， $Z_H = 2.44$

重合度系数 $Z\varepsilon$ ，由式 12.31, 因 $\varepsilon_\beta > 1,取\varepsilon_\beta = 1$, 故

$$Z\varepsilon=\sqrt{\frac{1}{\varepsilon_\alpha}}=\sqrt{\frac{1}{1.68}}=0.77$$

螺旋角系数 Z_β, $Z_\beta=\sqrt{\cos\beta}=\sqrt{\cos 13°32'10''}=0.99$

接触最小安全系数 $S_{H\min}$, 由表 12.14, 得 $S_{H\min}=1.05$ (一般可靠)

总工作时间 t_h, $t_h=4\times250\times16=16000h$

应力循环次数 N_L：

$$N_{L1}=60\gamma n_2 t_h=60\times1\times299.038\times16000=2.87\times10^8$$

$$N_{L2}=N_{L1}/i_2=2.87\times10^8/3.416=8.40\times10^7$$

接触寿命系数 Z_N, 由图 12.18, $Z_{N1}=1.10$, $Z_{N2}=1.16$

许用接触应力 $[\sigma_H]$

$$[\sigma_{H1}]=\frac{\sigma_{H\lim1}Z_{N1}}{S_{H\lim}}=\frac{710\times1.10}{1.05}=743.81MPa$$

$$[\sigma_{H2}]=\frac{\sigma_{H\lim2}Z_{N2}}{S_{H\lim}}=\frac{580\times1.16}{1.05}=640.76MPa$$

验算

$$\sigma_H=Z_E Z_H Z\varepsilon Z_\beta\sqrt{\frac{2KT_2}{bd_1^2}\cdot\frac{u+1}{u}}$$

$$=189.8\times2.44\times0.77\times0.99\times\sqrt{\frac{2\times3.54\times83767.45}{72\times72^2}\cdot\frac{3.416+1}{3.416}}$$

$$=505.97Mpa<[\sigma_{H2}]$$

计算结果表明, 接触疲劳强度较为合适, 齿轮尺寸无须调整.

4.2.3 确定传动主要尺寸

中心距 a $\quad a=\frac{d_1(i+1)}{2}=\frac{72\times(3.416+1)}{2}=158.976mm$

实际分度圆直径 d $\quad d_1=72mm, d_2=i_2d_1=3.416\times72=245.952mm$

齿宽 b $\quad b=\psi d_1=1.0\times72=72mm$, 取 $b_1=82mm, b_2=72mm$

齿根弯曲疲劳强度验算

齿形系数 $Y_{F\alpha}$: $Z_{V1}=\frac{Z_1}{\cos^3\beta}=\frac{28}{\cos^3 13°32'10''}10'=29$

$$Z_{V2}=\frac{Z_2}{\cos^3\beta}=\frac{96}{\cos^3\cos^3 13°32'10''}=99$$

由图 12.21, $Y_{F\alpha1}=2.55$, $Y_{F\alpha2}=2.19$

应力修正系数$Y_{S\alpha}$ ，由图 12. 22, $Y_{S\alpha1}=1.62$, $Y_{S\alpha2}=1.82$

重合度系数$Y\varepsilon$， $\varepsilon_{\alpha V}=\left[1.88-3.2(\frac{1}{Z_{V1}}+\frac{1}{Z_{V2}})\right]\cos\beta$

$$=\left[1.88-3.2(\frac{1}{29}+\frac{1}{99})\right]\cos 13°32'10''=1.69$$

$$Y\varepsilon=0.25+\frac{0.75}{\varepsilon_{\alpha V}}=0.25+\frac{0.75}{1.69}=0.69$$

螺旋角系数Y_{β}, $Y_{\beta\min}=1-0.25\varepsilon_{\beta}=1-0.25\times1=0.75$

（当$\varepsilon_{\beta}\geq1$时,按$\varepsilon_{\beta}=1$计算.）

$$Y_{\beta}=1-\varepsilon_{\beta}\frac{\beta}{120°}=1-1\times\frac{13.5°}{120°}=0.89>Y_{\beta\min}$$ ，故 $Y_{\beta}=0.89$

齿间载荷分配系数$K_{F\alpha}$, $\frac{\varepsilon_r}{\varepsilon_{\alpha}Y_{\varepsilon}}=\frac{3.83}{1.68\times0.69}=3.30$

前已求得 $K_{F\alpha}=1.75<\frac{\varepsilon_r}{\varepsilon_{\alpha}Y_{\varepsilon}}$, 故 $K_{F\alpha}=1.75$

齿向载荷分配系数$K_{F\beta}$, 由图 12. 14, $\frac{b}{h}=\frac{72}{2.25\times2.5}=12.8$, $K_{F\beta}=1.44$

载荷系数K, $K=K_AK_VK_{F\alpha}K_{F\beta}=1.25\times1.10\times1.75\times1.44=3.47$

弯曲疲劳极限, 由图 12. 23c, $\sigma_{F\lim1}=600MPa$, $\sigma_{F\lim2}=450MPa$

弯曲最小安全系数, 由表 12. 14, $S_{F\min}=1.25$

应力循环次数N_L, $N_{L1}=2.87\times10^8$, $N_{L2}=8.40\times10^7$

弯曲寿命系数Y_N, 由图 12. 24, $Y_{N1}=0.92$, $Y_{N2}=0.94$

尺寸系数Y_X, 由图 12. 25, $Y_X=1.0$

许用弯曲应力$[\sigma_F]$

$$[\sigma_{F1}]=\frac{\sigma_{F\lim1}Y_{N1}Y_X}{S_{F\min}}=\frac{600\times0.92\times1}{1.25}=441.6MPa$$

$$[\sigma_{F2}]=\frac{\sigma_{F\lim2}Y_{N2}Y_X}{S_{F\min}}=\frac{450\times0.94\times1}{1.25}=338.40MPa$$

验算

$$\sigma_{F1}=\frac{2KT_2}{bd_1m_n}Y_{F\alpha1}Y_{S\alpha1}Y_{\varepsilon}Y_{\beta}$$

$$=\frac{2\times3.47\times83767.45}{72\times72\times2.5}\times2.55\times1.62\times0.69\times0.89=113.80MPa<[\sigma_{F1}]$$

$$\sigma_{F2}=\sigma_{F1}\frac{Y_{F\alpha2}Y_{S\alpha2}}{Y_{F\alpha1}Y_{S\alpha1}}=113.80\times\frac{2.19\times1.82}{2.55\times1.62}=109.80Mpa<[\sigma_{F2}]$$

传动无严重过载,故不做静强度校核。

表 1　传动零件设计计算小结

名称	材料	硬度	齿数	齿宽	m_n	β	分度圆直径
齿轮Ⅰ	40Cr	260HB	22	55mm	2	12° 6′5′′	45.000mm
齿轮Ⅱ	45	240HB	105	45mm	2	12° 6′5′′	215.190 mm
齿轮Ⅲ	40Cr	280HB	28	82 mm	2.5	13° 32′10′′	72.000mm
齿轮Ⅳ	45	260HB	96	72mm	2.5	13° 32′10′′	254.952 mm

4.3 画简图

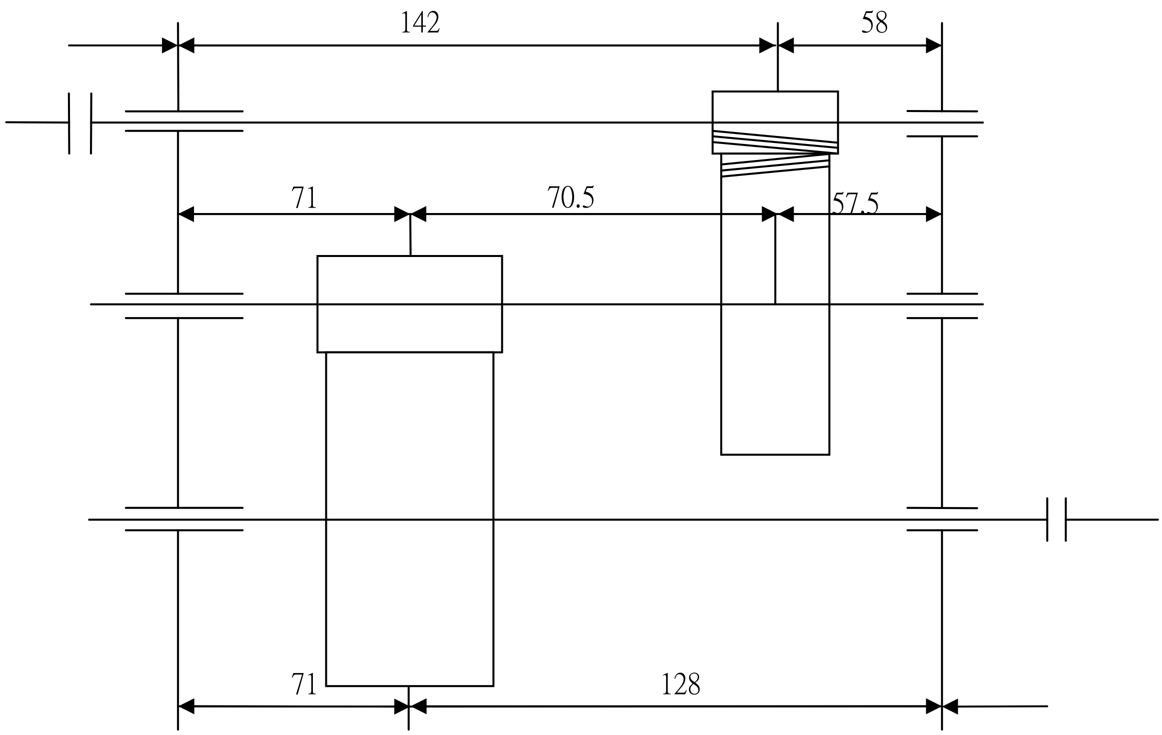


图 4.1 简图

4.3.1 初估轴径

在画装配草图前需初估轴径,从而提高设计效率,减少重复设计的工作量,并尽可能的降低生产成本。三根轴都选用 40Cr 材料。

由<<机械设计>>式 16.2,得各轴的最小直径分别为:

$$d_{\mathrm{I}} \geq C\sqrt[3]{\frac{P_{\mathrm{I}}}{n_{\mathrm{I}}}} = 102\sqrt[3]{\frac{2.731}{1430}} = 12.655mm$$

$$d_{\mathrm{II}} \geq C\sqrt[3]{\frac{P_{\mathrm{II}}}{n_{\mathrm{II}}}} = 102\sqrt[3]{\frac{2.623}{299.038}} = 21.036mm$$

$$d_{\mathrm{III}} \geq C\sqrt[3]{\frac{P_{\mathrm{III}}}{n_{\mathrm{III}}}} = 102\sqrt[3]{\frac{2.493}{87.537}} = 31.149mm$$

式中: C 为轴强度计算系数,40Cr 所对应的系数为 102

考虑到实际情况,可将这三轴的最小轴径定为 25mm,50mm 和 35mm。

4.3.2 初选联轴器

联轴器除联接两轴并传递转矩外,有些还具有补偿两轴因制造和安装误差而造成的轴线偏移的功能,以及具有缓冲、吸振、安全保护等功能。电动机轴和减速器高速轴联接用的联轴器,由于轴的转速较高,为减小启动载荷,缓和冲击,应选用具有较小转动惯量和具有弹性的联轴器,该设计选用弹性柱销联轴器。减速器低速轴与工作机联接用的联轴器,由于轴的转速较低,不必要求具有较小的转动惯量,但传递转矩较大,又因减速器与工作机不在同一底座上,要求具有较大的轴线偏移补偿,因此选用鼓形齿式联轴器。根据上述分析并考虑到实际情况,联轴器选择如下: 电动机轴和减速器高速轴联接用的联轴器选用 LT4 联轴器 $\frac{J_1 28\times 44}{J_1 25\times 44}$ $GB/T4323-2002$。

4.3.3 初选轴承

轴承是支承轴颈的部件。由于该传动装置采用两对斜齿轮传动，经比较选择，采用两对角接触球轴承和深沟球轴承。从高速轴到低速轴，选用的轴承分别为 7307C、30210、30210，均为成组使用，面对面安装。

5 轴的校核计算

5.1 高速轴受力分析

高速轴受力情况如下：

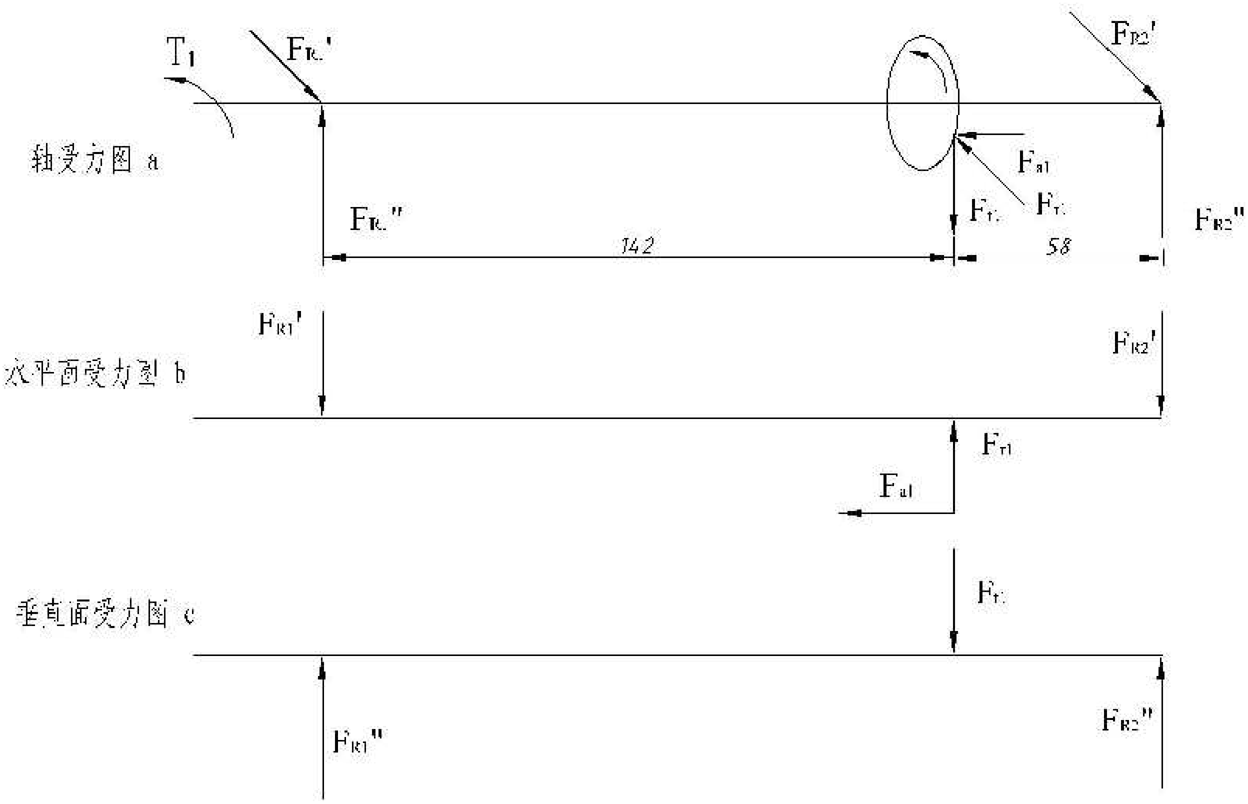


图 5.1 高速轴受力情况

$$F_{t1}=\frac{2T_1}{d_1}=\frac{2\times18238.50}{45}=810.60N$$

$$F_{r1}=\frac{F_{t1}\tan\alpha_n}{\cos\beta}=\frac{810.60\tan20°}{\cos12°6'5"}=301.74N$$

$$F_{a1}=F_{t1}\tan\beta=810.60\times\tan12°6'5"=173.80N$$

水平受力分析:

对 F_{R2}'作用点取矩,则有

$$F_{R1}'=\frac{F_{r1}\times58+F_{a1}\times\frac{d_1}{2}}{200}=\frac{301.74\times58+173.80\times22.5}{200}=107.06N$$

对 F_{R1}' 作用点取矩，则有

$$F_{R2}'=\frac{F_{r1}\times 142-F_{a1}\times \frac{d1}{2}}{200}=\frac{301.74\times 142-173.80\times 22.5}{200}=194.68N$$

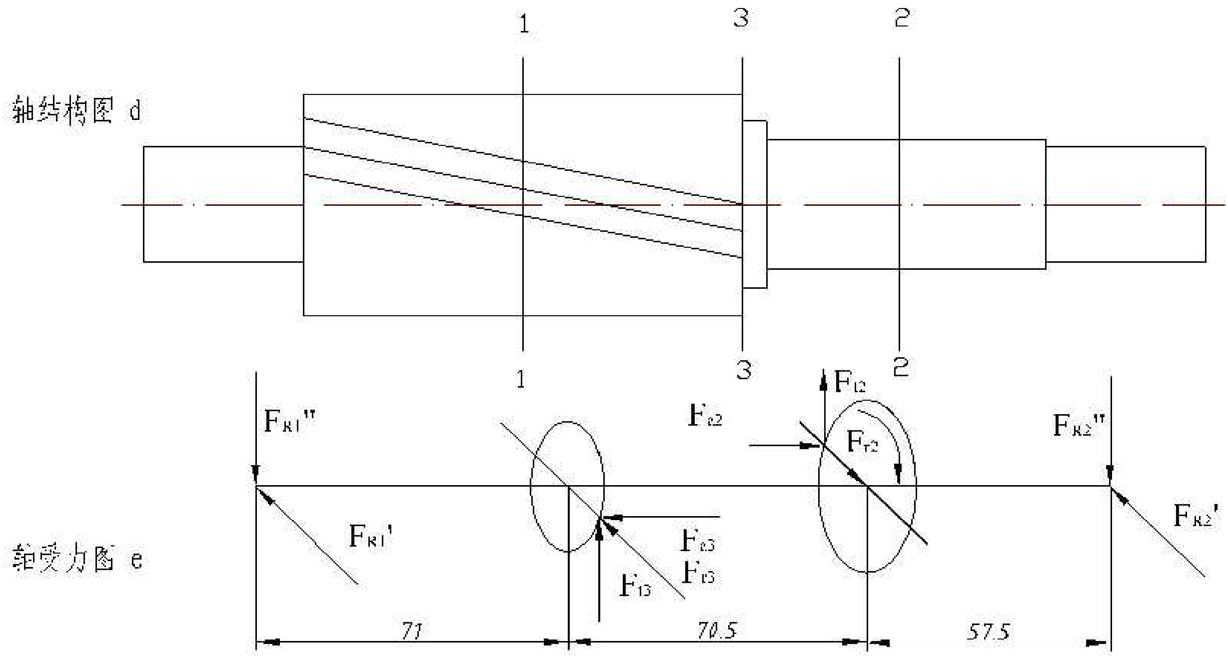
垂直面受力分析:

对 F_{R2}'' 作用点取矩，则有: $F_{R1}''=\frac{F_{t1}\times 58}{200}=\frac{810.60\times 58}{200}=235.07N$

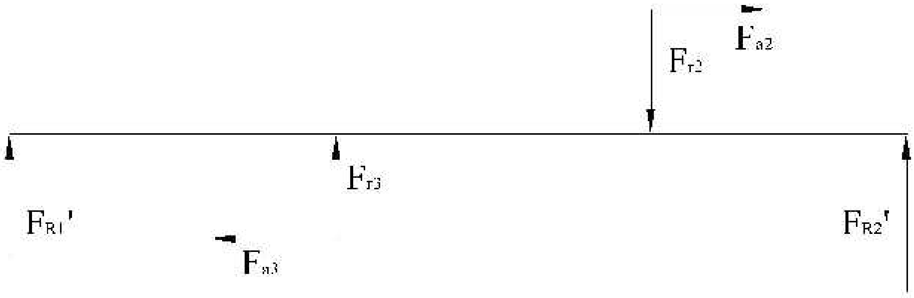
对 F_{R1}'' 作用点取矩，则有: $F_{R2}''=\frac{Ft1\times 142}{200}=575.53$

5.2 中间轴校核计算

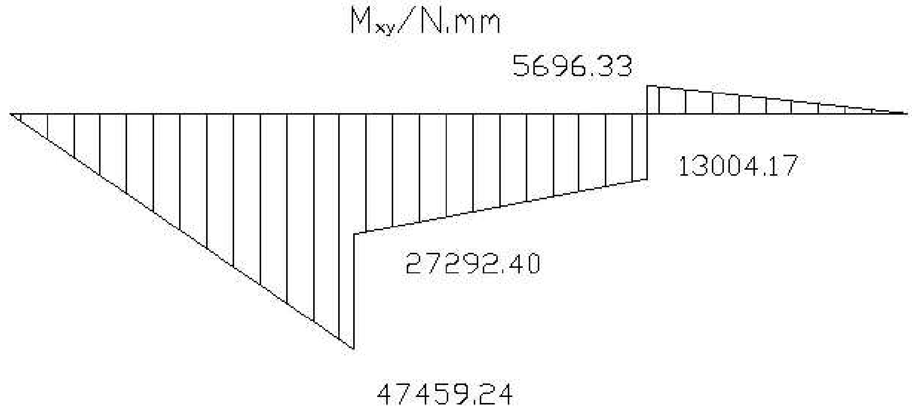
中间轴结构和受力分析图如下:



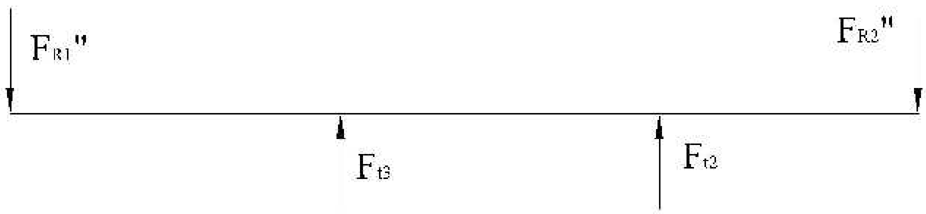
水平面受力图 f



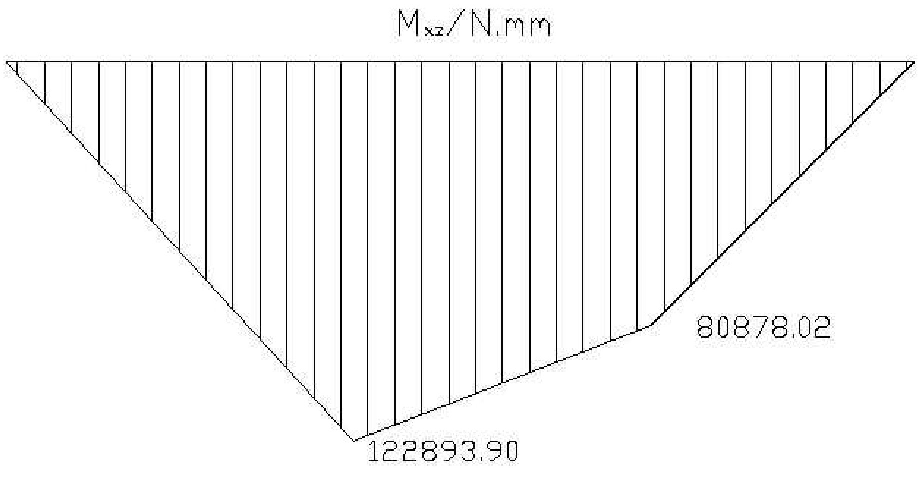
水平面弯矩图 g



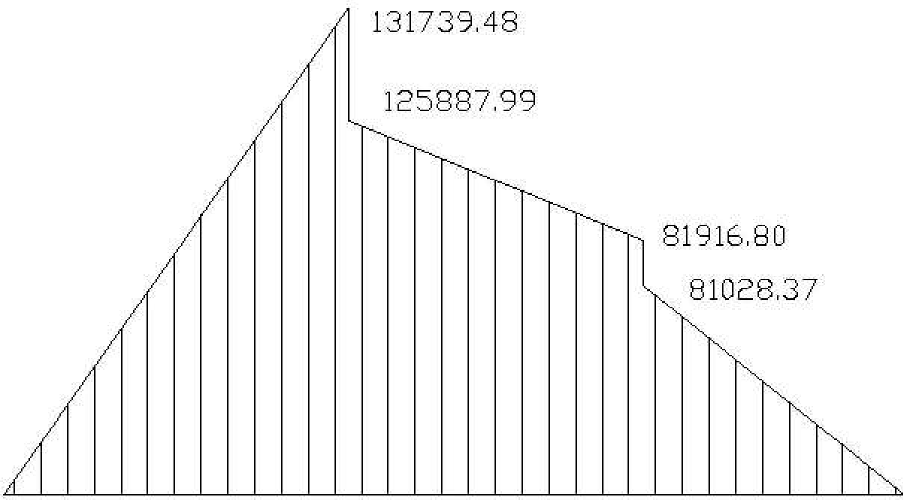
垂直面受力图 h



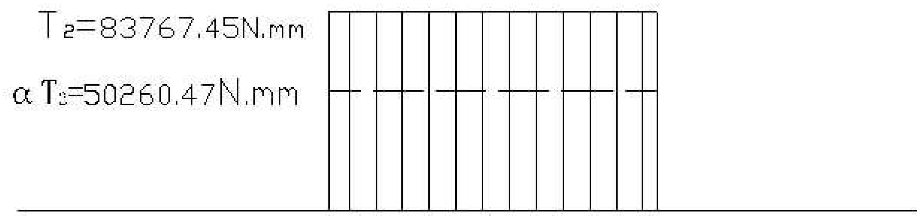
垂直面弯矩图 i



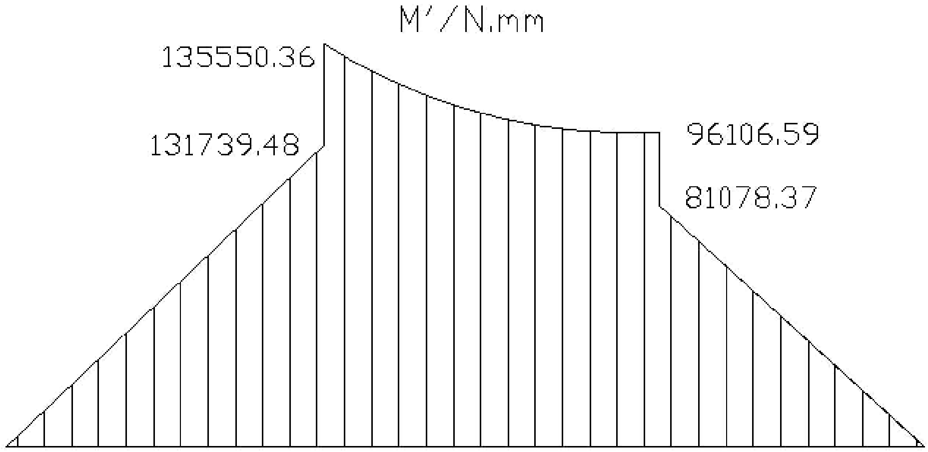
合成弯矩图 j



转矩图 k



当量弯矩图 l



中间轴材料选用 40Cr 调质，$\sigma_B = 750MPa, \sigma_S = 550MPa$。轴的弯曲应力校核步骤如下：

计算齿轮受力

齿轮Ⅱ所受的力（$\beta_1 = 12°6'5''$）：

圆周力 $F_{t2} = F_{t1} = 810.60N$

径向力 $F_{r2} = F_{r1} = 301.74N$

轴向力 $F_{a2} = F_{a1} = 173.80N$

转矩 $T_2 = 83767.45N \cdot mm$

齿轮Ⅲ所受的力：（$\beta_2 = 13°32'10''$）

圆周力 $F_{t3}=\dfrac{2T_2}{d_3}=\dfrac{2\times83767345}{72}=2326.87N$

径向力 $F_{r3}=\dfrac{F_{t3}\tan20^\circ}{\cos\beta}=\dfrac{2326.87\tan20^\circ}{\cos13^\circ32'10''}=871.11N$

轴向力 $F_{a3}=F_{t3}\tan\beta_2=2326.87\times\tan13^\circ32'10''=560.19N$

计算支承反力

水平面反力

$$F_{R1}'=\frac{F_{r2}\times57.5-F_{a2}\times\dfrac{215.190}{2}-F_{r3}\times128-F_{a3}\times\dfrac{72}{2}}{199}$$

$$=\frac{301.74\times57.5-173.80\times\dfrac{215.190}{2}-871.11\times128-560.19\times\dfrac{72}{2}}{199}=-668.44N$$

$$F'_{R2}=\frac{F_{a2}\times\dfrac{d_2}{2}+F_{r2}\times141.5-F_{r3}\times71+F_{a3}\times\dfrac{d_3}{2}}{199}$$

$$=\frac{173.80\times\dfrac{215.190}{2}+301.74\times141.5-871.11\times71+560.19\times\dfrac{72}{2}}{199}=99.07N$$

垂直面反力

$$F_{R1}''=\frac{F_{t3}\times128+F_{t2}\times57.5}{199}=1730.90N$$

$$F_{R2}''=\frac{F_{t3}\times71+F_{t2}\times141.5}{199}=\frac{2326.87\times71+810.6\times141.5}{199}=1406.57N$$

水平面受力图, 如 f 图所示

垂直面受力图, 如 h 图所示

画轴弯矩图

水平面弯矩图, 如 g 图所示， M_{xz} 图

垂直面弯矩图, 如 i 图所示， M_{xy} 图

合成弯矩图, 如 j 图所示，合成弯矩 $M=\sqrt{M_{xy}^2+M_{xz}^2}$

画轴转矩图

轴受转矩 $T=T_2=83767.45N\cdot mm$

转矩图， 当量转矩图，如图 k 所示

$\alpha T=0.60\times83767.45=50260.47N\cdot mm$

许用应力

用插入法由表 16. 3, 查得$\left[\sigma_{-1b}\right]=70MPa,\left[\sigma_{0b}\right]=120MPa$

应力校正系数 $\alpha=\frac{\left[\sigma_{-1b}\right]}{\left[\sigma_{0b}\right]}=\frac{70}{120}\approx 0.60$

画当量弯矩图

当量弯矩:

在齿轮III中间处$M_1'=\sqrt{M^2+(\alpha T)^2}=135550.36N\cdot mm$

在齿轮II(轴头)中间处$M_2'=\sqrt{M^2+(\alpha T)^2}=96106.59N\cdot mm$

当量弯矩图, 见图 1

校核轴径

齿根圆直径 $d_{f3}=d_3-2\times(h_a+c)m_n=72-2\times1.25\times2.5=65.75mm$

轴径 $d_{1-1}=\sqrt[3]{\frac{M_1'}{0.1\left[\sigma_{-1b}\right]}}=\sqrt[3]{\frac{135550.36}{0.1\times70}}=26.85mm$

$$d_{2-2}=\sqrt[3]{\frac{M_2'}{0.1\left[\sigma_{-1b}\right]}}=\sqrt[3]{\frac{96106.59}{0.1\times70}}=23.95mm$$

经检验轴所用尺寸合格。

中间轴安全系数校核计算如下：

以齿轮III端面处危险截面为例进行安全系数校核。

对称循环疲劳极限 $\sigma_{-1b}=0.44\sigma_B=0.44\times750=330MPa$

$$\tau_{-1}=0.30\sigma_B=0.30\times750=225MPa$$

脉动循环疲劳极限 $\sigma_{0b}=1.7\sigma_{-1b}=1.7\times330=561MPa$

$$\tau_0=1.6\tau_{-1}=1.6\times225=360MPa$$

等效系数 $\psi_\sigma=\frac{2\sigma_{-1b}-\sigma_{0b}}{\sigma_{0b}}=\frac{2\times330-561}{561}=0.18$

$$\psi_{\tau}=\frac{2\tau_{-1}-\tau_{0}}{\tau_{0}}=\frac{2\times225-360}{360}=0.25$$

截面 3-3 上的应力

水平面弯矩

$$Mxy=F_{R1}'\times112+F_{a3}\times\frac{d_3}{2}+F_{r3}\times41$$

$$=-668.44\times112+560.19\times\frac{72}{2}+871.11\times41=-18982.93N\cdot mm$$

垂直面弯矩

$$Mxz=-F_{R1}''\times112+F_{t3}\times41$$

$$=-1730.90\times110+2326.87\times41=-98459.13N\cdot mm$$

合成弯矩

$$M=\sqrt{Mxy^2+Mxz^2}=100282.39N\cdot mm$$

$$=\sqrt{(-18982.93)^2+(-98459.13)^2}=100272.39N\cdot mm$$

弯曲应力幅　　$\sigma_a=\sigma=\frac{M}{W}=\frac{100272.39}{0.1\times64^3}=3.83MPa$

弯曲平均应力　　$\sigma_m=0$

扭转切应力　　$\tau=\frac{T_2}{W_T}=\frac{83767.45}{0.2\times64^3}=1.60MPa$

扭转切应力幅和平均切应力　　$\tau_a=\tau_m=\frac{\tau}{2}=0.80MPa$

应力集中系数

有效应力集中系数

因在此截面处，有轴径变化，过渡圆角半径 r=1mm，由

$D/d=65.75/64=1.02, r/d=1/64=0.02$ 和 $\sigma_B=750MPa$，从附录表 1 中查出

$k_\sigma=2.14, k_\tau=1.39$。

表面状态系数　　由附录 5 查出 $\beta=0.86$

尺寸系数　　由附录 6 查出 $\varepsilon_\sigma=0.68, \varepsilon_\tau=0.74$

安全系数

弯曲安全系数　　设为无限寿命，$k_N=1$，由式 16.5 得

$$S_\sigma=\frac{k_N\sigma_{-1b}}{\frac{k_\sigma}{\beta\varepsilon_\sigma}\sigma_a+\psi_\sigma\sigma_m}=\frac{1\times 330}{\frac{2.14}{0.86\times 0.68}\times 3.83}=23.55$$

扭转安全系数
$$S_\tau=\frac{k_N\tau_{-1}}{\frac{k_\sigma}{\beta\varepsilon_\tau}\tau_a+\psi_\tau\tau_m}=\frac{1\times 225}{\frac{1.39}{0.86\times 0.74}\times 0.80+0.25\times 0.80}=115.54$$

复合安全系数

$$S=\frac{S_\sigma S_\tau}{\sqrt{S_\sigma^2+S_\tau^2}}=\frac{23.55\times 115.54}{\sqrt{23.55^2+115.54^2}}=23.08$$

经检验轴所用尺寸合格。

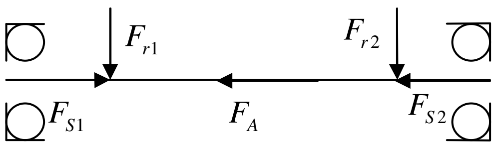
轴承验算

6 高速轴轴承验算

查手册 7307c 轴承主要性能参数如下：

$C_r = 32.8KN, C_{or} = 24.8KN, N_o = 75000r/\min$(脂润滑)，$e = 0.68$

寿命计算



左边轴承径向力 $F_{r1} = \sqrt{107.06^2 + 235.07^2} = 258.30N$

右边轴承径向力 $F_{r2} = \sqrt{194.68^2 + 575.53^2} = 607.56N$

轴向力 $F_A = F_{a1} = 173.80N$，方向向左

附加轴向力 查表 18.4，可得

$F_{s1} = 0.68F_{r1} = 175.64N$， $F_{s2} = 0.68F_{r2} = 413.14N$

因 $F_{s2} + F_A = 413.14 + 173.80 > F_{s1}$，故左边轴承被压紧

轴承轴向力 $F_{a1} = F_{s2} + F_A = 413.14 + 173.80 = 586.94N$

$F_{a2} = F_{s2} = 413.14N$

X,Y 值 $F_{a1}/F_{r1} = 586.94/258.30 = 2.27 > e$，故 $X_1 = 0.41, Y_1 = 0.87$

$F_{a2}/F_{r2} = 413.14/607.56 = 0.68 = e$，故 $X_2 = 1, Y_2 = 0$

冲击载荷系数 考虑中等冲击查表 18..8 得 $f_d = 1.2$

当量动载荷

$$P_1 = f_d(X_1F_{r1} + Y_1F_{a1}) = 1.2\times(0.41\times258.30 + 0.87\times586.94) = 739.85N$$
$$P_2 = fd(X_2Fr_2 + Y_2Fa_2) = 1.2\times(1\times607.56 + 0) = 729.07N$$

轴承寿命 因 $P_1 > P_2$，只计算轴承 1 的寿命

$$L_{10}h = \frac{16670}{n}(\frac{Cr}{P_1})^3 = \frac{16670}{1430}\times(\frac{32800}{739.85})^3 = 1.02\times10^6 h > 8\text{年}$$

故高速级轴承满足寿命要求。

静载荷计算

X₀、Y₀ 查表 18.12，得 $X_0=0.5$， $Y_0=0.38$

当量静载荷

$$\left.\begin{aligned}P_{0r1}&=X_0F_{r1}+Y_0F_{a1}\\&=0.5\times258.30+0.38\times586.94=352.19N\\P_{0r1}&=F_{r1}=258.30N\end{aligned}\right\}\text{取大者}$$

$$\left.\begin{aligned}P_{0r2}&=X_0F_{r2}+Y_0F_{a2}\\&=0.5\times607.56+0.38\times413.14=460.77N\\P_{0r2}&=F_{r2}=607.56N\end{aligned}\right\}\text{取大者}$$

安全系数 S_0 正常使用角接触球轴承，查表 18.14，得 $S_0=1.5$

计算额定静载荷 $C'_{0r2}=S_0P_{0r2}=1.5\times607.56=911.34N$

（因 $P_{0r1}<P_{0r2}$,故只计算轴承2）

许用转速验算

载荷系数 f_1 $\dfrac{P_1}{C_{r1}}=\dfrac{739.85}{32800}=0.023$,查图18.19,得$f_{11}=1$

$\dfrac{P_2}{C_{r2}}=\dfrac{729.07}{32800}=0.022$,查图18.19,得$f_{12}=1$

载荷分布系数 f_2

$\dfrac{F_{a1}}{F_{r1}}=\dfrac{586.94}{258.30}=2.27$,查图18.20,得$f_{21}=0.96$

$\dfrac{F_{a2}}{F_{r2}}=\dfrac{413.14}{607.56}=0.68$,查图18.20,得$f_{22}=0.99$

许用转速 N $N_1=f_{11}f_{21}N_0=1\times0.96\times7500=7200\,r/\min$

$N_2=f_{12}f_{22}N_0=1\times0.99\times7500=7425\,r/\min$

均大于工作转速 1430r/min。

经检验该轴承合格。

致　谢

本论文是在杨世平老师的悉心指导和热情关怀下完成的。在整个设计过程中，不仅在学业上得到了老师细致、耐心的教导和讲解，使自己巩固、完善了所学知识，并且治学严谨、塌实沉稳的学风给人以深厚影响，在我的学习、待物中产生了积极作用，也使得本次设计能够顺利完成。

再此衷心感谢在这过程中帮助及指导过我的老师和同学，让我开阔了眼界，增加了学识。

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附录 1　外文文献翻译

工艺规程制订与并行工程

T. Ramayah and Noraini Ismail

摘要:产品设计是用于产品，及它的部件装配的计划。为了把产品设计转换成一个实际物体，这需要一个制造计划。而制订一个这样的计划的行动就叫做工艺规程制订。它是产品设计和制造之间的连接，工艺规程制订包括决定加工顺序和制造产品所必须完成的装配步骤。在以下文章中,我们将解释工艺规程制订和他的一些相关主题

文章开始，我们应该区别在下列文章中被反复提到的工艺规程制订和生产计划。工艺规程制订与如何制造产品和它的零件等工程技术问题有关，制造零件和装配产品需要什么样的设备和工具？工艺规程制订与产品制造物流管理有关系。它在工艺规程制订后面与原料分类及获得满足制造充分数量产品要求的资源有关。

工艺规程制订

工艺规程制订包括决定最适当的制造及装配步骤和顺序，在这些顺序和步骤中他们必须根据所提出的详细的设计说明书规范完成给定零件或产品制造。 能够被计划的工艺范围和多样性通常由于公司车间可用设备和技术能力而受到限制。在公司内部不能够制造的零件必须到外部市场购买，工艺规程制订所提及的工艺选择同样也受到详细设计资料的限制，我们稍后将会回到这一点。

工艺规程制订通常是由制造工程师完成的，工艺制订者必须熟悉工厂中详细可用的制造流程并且能够说明工程图。基于制订者的知识、技术和经验，用于制造每个零件的工艺步骤以最合乎逻辑的顺序被发展制订。下列各项是在工艺规程制订范围里的许多决定和详细资料：

.设计图的说明.　　在工艺规程制订的开始，产品设计的这一部分(材料、尺寸、公差、表面处理等等)必须进行分析。

.工艺和顺序.　　工艺制订者必须选择哪一个工艺是必需的及必需工艺的序列。此外还必须准备好一个简短的工艺步骤描述。

.设备选择.　　大体上，工艺制订者必须逐步展开利用工厂现有机器的计划。另外，组件必须被购买或在新设备上的投资必须被制定。

.工具、冲模、铸模、夹具、量具.　　工艺必须决定每个工序需要什么工具，这些工具的实际设计和制造通常通过委派工具设计部门和工具库或者联系专攻那种工具制造的外面厂商来完成。

.方法分析.　　车间规划，小工具，提升重物的提升间。甚至在一些人工操作情景中的肢体动作也被指定。

.操作步骤.　　工作测量技术被用来为每个操作设定时间标准。

.切削工具和切削条件.　　这些必须对加工操作通过推荐标准手册来进行详细说明。

零件工艺规程制订

对于单个零件，加工顺序通过一种被称为进路表的表格来进行文件证明备份。就如工程图被用于详细说明设计产品一样，进路表被用于详细说明工艺计划。他们是类似的，一个用于产品设计，另一个用于制造。

制造单个零件的典型加工顺序包括：(1) 一个基本工序 (2) 二级工序 (3) 提高物质特性工序和(4) 最后工序。一个基本工序决定了工件的起始造型。金属铸件、塑料成型、金属精炼是基本工序中的实例。起始造型常常必须通过改变起始造型操作(或者接近于最终造型)的二级工序来精制。二级工序习惯于和基本工序一起提供起始造型，当砂型铸造是基本工序，车加工通常是二级工序。当轧钢厂制造金属片是基本工序，冲压操作像冲裁和弯曲通常是二级工序。当塑料注入成型是基本工序时，二级工序通常是不必要的，因为他的大多数几何特征制造通过别的方式如成型制造来完成。塑料成型和其他操作的二级工序被称为净成型工序的并发二级工序，需要一些但并不多的二级工序的操作就是所提到的近似成型工序。许多有印象的摸锻件就是这一类，这类零件能够经常在锻造(初级工序)阶段被成型，因此减少了必要的加工(二级工序)。

一旦模型被建立，许多零件的下一步是改良它们的机械物理性能。提高特性工序并不改变零件模型，然而，它却能改变零件的物理特性。金属零件的热处理操作就是最普通的实例。类似的如玻璃通过热处理来制造钢化玻璃，对于大多数零件的制造来说，这些特性加强工序在加工工序中并不需要。

最后工序通常对零件(或装配体)的表面提供一个涂层。例如电镀、薄膜沉积技术、涂漆。表面处理的目的是改善外观，改变颜色

或者表面保护防止腐蚀和磨损等等。在很多零件中最后工序是并不需要的。例如：塑料成型就很少需要最后程序。当必须需要最后程序，他通常是加工顺序的最后一步。

装配工艺规程制订

一个既定产品的典型装配方法由以下因素决定的：(1)预期产品数量(2)装配产品的复杂性。例如：不同组件的数量和(3)常用装配工艺。例如：机械定位焊接、对于小数量产品，通常在人工装配线上进行装配。对于大量制造的一打或这样组件的简单零件，要采用适当的自动化装配线。无论如何这里有一个工作必须被完成的优先顺序，这个优先需求经常用一个优先表来进行图表描绘。

装配工艺规程制订包括装配指令的发展，但是更详细地对于小批量生产。在一个岗位完成整个装配，对于一个装配线上的大批量生产，工艺规程制订由一种分配工作条件到装配线个别工位并被叫做人工投入线性平衡法的程序组成。这种装配线按照装配线平衡解决方案决定的顺序发送工作单元到个别工位，在个别组成，任意工具或夹具的工艺规程制订时，一条装配线的决定、设计和制造必须被完成，并且工作站的必须被列出来。

制造或购买决定

在工艺制定过程中出现的一个重大问题是一个特定零件应该在公司内部的工厂内生产还是从外部销售商处购买，并且这个问题的答案被认为是制造或购买决定。如果公司没有技术设备或制造零件所必须的详细制造工艺中的专门技术，那么答案就很明显了。因为没有其他选择零件必须购买。然而，在很多例子中零件既可以在利用现有设备在内部制造或者可以从外部拥有相似制造能力的生产销售商处购买。

在我们的关于制造或购买的决定的讨论中，他应该认识到在开始几乎所有的制造者从供应商那里购买原料。一个机械加工厂从一个金属经销商购买他的起动柄原料或从一个铸造厂购买他的砂型铸件。一个塑料成型厂从一个化工厂购买他的模塑料。一个冲压厂可以去经销商或直接从轧钢厂购买金属片。很少的公司能够在操作中从原料一直进行垂直整合，这看来至少购买一些也许在他的工厂可以另外制造的零件是合理的。也有可能为公司使用的每一个组成要求制造或购买决定。

这里有许多影响制造或购买决定的因素，一个人可能认为成本是决定是购买还是制造零件的最重要的因素。如果一个外部经销商比公司工厂更精通于制造零件的工艺，因而公司内部生产成本可能比经销商赚取成本后的价格还要高。可是，如果购买决定导致

公司工厂设备和劳动的闲置，购买零件的表面优势就会丧失。考虑以下例子制造或购买决定。

为一个特定零件被引述的价格是 100 个单位的每单位$20.00。制造零件的成分如下所示：

单位原料成本=每单位$8.00

直接劳动成本=每单位$6.00

劳动加班 150%=每单位$9.00

设备修理成本=每单位$5.00

总计=每单位$28.00

这个组成应该被购买还是在内部制造？

解决方案：尽管经销商的引证似乎支持购买决定，让我们来考虑如果引证被接受可能在生产操作中的冲突。$5.00 设备维修成本是已经被制定的投资成本，如果设备设计因为购买零件的决定而变的没有利用价值，那么这个固定成本仍然继续尽管设备闲置着。同样，如果零件被购买由工厂空间，效用和劳动成本组成的$9.00 的劳动间接成本仍然继续。通过这种推理，如果应该已用于生产零件的设备闲置的购买决定并不是一个好决定因为他可能花费公司将近$20.00+$5.0+$9.00=$34.0 每单元。另一方面，如果正在讨论的设备可以被用于生产其他零件并且内部生产成本低于外部联系报价，那么一个购买决定就是一个好决定。

制造或购买决定并不像这个例子中的那样直接。这几年的一个趋势，尤其在汽车工业，公司和零件供应者建立紧密关系。由此我们将引出并行工程。

在计划操作方面制造公司有很大兴趣利用计算机辅助工艺（CAPP）系统来完成。

那些熟悉加工详细资料和其他工艺的工厂培训的工人逐渐退休，并且这些人在将来工艺制订的过程中是非常有用的。一种可选择的用于完成这种功能的方式是必需的，CAPP 提供了这种选择。CAPP 经常被看作是计算机辅助制造（CAM）的一部分。然而这种趋向意味着 CAM 是一系列系统。事实上，当 CAD 和计算机辅助设计协同作用创

造了一个 CAD/CAM 系统。在这样一个系统中，CAPP 成为设计和制造之间的直接联结。来自计算机辅助工艺的优点包括以下几点：

.工艺合理化和标准化.　　自动工艺规程制订比完全用手工编制工艺产生的更合理化和一致化。标准设计趋向产生低成本和高生产质量。

.增强工艺制订者的生产力.　　在数据文件中的系统方法和标准加工设计的实用性使工艺制订者可完成更多的工作。

.减少工艺规程的制订时间.　　与手工准备相比，利用 CAPP 系统的工艺制订者可以在较短的时间内准备好进路表。

.改良异读性.　　计算机准备的进路表比手工准备的进路表更容易简洁。

.结合其他应用软件.　　CAPP 系统可以在界面上与其它应用软件结合，象成本估计和工作标准。

计算机辅助工艺围绕着两个路径来设计，这两个路径被叫做：（1）CAPP 检索系统和（2）CAPP 生成系统。许多 CAPP 系统结合这两种路径而被称为生成检索 CAPP 系统。

制造业的并行工程和设计

并行工程引用一种常用于产品发展的路径，通过它使工程设计功能、工程制造功能和其他功能综合起来以减少一种新产品投放市场所需要的共用时间，也被称为并发工程，他可能被认为是 CAD/CAM 技术的类似组织版本，按照传统路径来使一件产品投放市场。如图(1)a 所示，工程设计功能和工程制造功能这两种功能是分开并且连续的，产品设计部门开展一项新的设计有时很少考虑到公司的制造能力，也很少有机会能够让制造工程师来提供如何使设计更容易制造的一些建议。他好像消除了在设计和制造之间的一堵墙，当设计部门完成设计，他投掷工程图和说明书越过这面墙，并且那时工艺规程制订也开始了。

图（1）比较 ：(a) 传统产品发展周期和 (b) 并行产品的发展周期

通过比较，实行并行工程的公司，工程制造部门在早期就参与到产品发展周期。为如何使产品和他的组成能够被设计的更适于制造提供建议。他同样为产品提供制造计划

继续进行的早期准备，这种并行工程的路径在图(1)b 中被描绘出。除了工程制造以外其他功能同样被包括在产品发展周期中，如质量工程、制造部门、后勤服务、市场供应评定组成和一些情况下将使用这些产品的消费者。在产品发展阶段的所有这些功能不仅能改善新产品的功能和性能，同时也能改善他的可造性、自检性、易测性、服务能力和可维护性。通过早期功能改善，因为在最终产品设计之后的回顾太晚以至于不能对设计进行便利的修改的不利因素的消除，使产品发展周期的持续期大大减少。

并行设计包含以下因素：(1)一些制造和装配设计(2)质量设计(3)成本设计和(4)生命周期设计。另外，像快速成型、虚拟制造、和组织转变等辅助技术需要被用来促进公司的并行工程。

制造和装配设计

据估计一件产品的 70%的生命周期成本是由在产品设计时所做的基本决定所决定的，这些设计决定包括每个零件的材料、零件模型、公差、表面处理、零件是如何被组织装配的和常用装配方法。一旦这些决定被指定，减少产品制造成本的能力就会被限制。例如，如果产品设计者决定用铝砂型铸造法制造一个分开零件，但是这个零件的工艺特性只能通过加工来完成(如螺纹孔和配合公差)，制造工程师没有选择的余地，只能按照先砂型铸造在加工的方法来达到既定要求。在这个例子中，用一个在单独步骤所需要的塑料模制品也许是一个较好的决定。因此，当产品设计展开时给制造工程师

一个忠告设计者的机会对产品的顺利可造性是非常重要的。

这种被用于尝试描述顺利改变一件新产品的可造性的条件是制造设计(DFM)和装配设计(DFA)。当然，DFM 和 DFA 是紧密相连的，因此让我们用制造和装配设计(DFM/A)的形式来表达。制造和装配设计包括在一件新产品中的可造性和可装配性的综合考虑，这包括： (1)组织变化和(2)设计原理和指导方针。

.在 DFM/A 中的组织变化.　 DFM/A 的有效执行包括公司组织机构的正式或非正式的变化，因此设计职工和制造职工之间有很好的交流和交互作用。这可以通过以下方法来完成：(1)通过成立由产品设计者制造工程师和其他员工(例如：质量工程师、材料专家)组成的攻关小组来进行产品开发；(2)通过要求设计工程师用一些事业时间在制造上，以能够掌握第一手可造性和可装配性是如何通过产品设计联系在一起的；(3)通过指派制造工程师到产品设计部门在一个临时的或专任的基础上做一个还原性顾问。

.设计说明和指导方针.　　DFM/A 为了理解如何设计一个既定产品来使可造性和可装配性最大化也依赖于设计说明和指导方针的使用，这些通用设计指导方针中的一些几乎适用于任何产品设计。在其他方面，一些设计原理只适用于特定工序，例如：轴或锥度在阶梯中的使用和利用模制品来切除模内零件，在制造过程中我们只把这些具体过程指导方针放在书本上。

指导方针有时互相矛盾，一条指导方针是“简化零件模型，避免不必要的特征”。但是在同一表格里的另一指导方针为了装配安全而规定在设计产品时“特殊几何特征必须不时加上他的组成”。而且他也许值得来结合个别装配件的特征来减少产品中零件的数量。在这些示例中零件制造设计与装配设计相冲突，在这个矛盾冲突的两边，一个适当解决方法必须被发现。

附录 2　外文文献原文

Process Planning and Concurrent Engineering

T. Ramayah and Noraini Ismail

Abstract:The product design is the plan for the product and its components and subassemblies. To convert the product design into a physical entity, a manufacturing plan is needed. The activity of developing such a plan is called process planning. It is the link between product design and manufacturing. Process planning involves determining the sequence of processing and assembly steps that must be accomplished to make the product. In the present chapter, we examine processing planning and several related topics.

Process Planning

Process planning involves determining the most appropriate manufacturing and assembly processes and the sequence in which they should be accomplished to produce a given part or product according to specifications set forth in the product design documentation. The scope and variety of processes that can be planned are generally limited by the available processing equipment and technological capabilities of the company of plant. Parts that cannot be made internally must be purchased from outside vendors. It should be mentioned that the choice of processes is also limited by the details of the product design. This is a point we will return to later.

Process planning is usually accomplished by manufacturing engineers. The process planner must be familiar with the particular manufacturing processes available in the factory and be able to interpret engineering drawings. Based on the planner’s knowledge, skill, and experience, the processing steps are developed in the most logical sequence to make each part. Following is a list of the many decisions and details usually include within the scope of process planning.

The part of product design must be analyzed (materials, dimensions, tolerances, surface finished, etc.) at the start of the process planning procedure.

The process planner must select which processes are required and their sequence. A brief description of processing steps must be prepared.

In general, process planners must develop plans that utilize existing equipment in the plant. Otherwise, the component must be purchased, or an investment must be made in new equipment.

The process must decide what tooling is required for each processing step. The actual design and fabrication of these tools is usually delegated to a tool design department and tool room, or an outside vendor specializing in that type of tool is contacted.

Method analysis Workplace layout, small tools, hoists for lifting heavy parts, even in some cases hand and body motions must be specified for manual operations. The industrial engineering department is usually responsible for this area.

Work standards. Work measurement techniques are used to set time s

Cutting tools and cutting conditions. These must be specified for machining operations, often with reference to standard handbook recommendations.

Process planning for parts

For individual parts, the processing sequence is documented on a form called a route sheet. Just as engineering drawings are used to specify the product design, route sheets are used to specify the process plan. They are counterparts, one for product design, for manufacturing.

A typical processing sequence to fabricate an individual part consists of: (1) a basic process, (2) secondary processes, (3) operations to enhance physical properties, and (4) finishing operations. A basic process determines the starting geometry of the work parts. Metal casting, plastic molding, and rolling of sheet metal are examples of basic processes. The starting geometry must often be refined by secondary processes, operations that transform the starting geometry (or close to final geometry). The secondary geometry processes that might be used are closely correlated to the basic process that provides the starting geometry. When sand casting is the basic processes, machining operations are generally the second processes. When a rolling mill produces sheet metal, stamping operations such as punching and bending are the secondary processes. When plastic injection molding is the basic process, secondary operations are often unnecessary, because most of the geometric features that would otherwise require machining can be created by the molding operation. Plastic molding and other operation that require no subsequent secondary processing are called net shape processes. Operations that require some but not much secondary processing (usually machining) are referred to as near net shape processes. Some impression die forgings are in this category. These parts can often be shaped in the forging operation (basic processes) so that minimal machining (secondary processing) is required.

Once the geometry has been established, the next step for some parts is to improve their mechanical and physical properties. Operations to enhance properties do not alter the geometry of the part; instead, they alter physical properties. Heat treating operations on metal parts are the most common examples. Similar heating treatments are performed on glass to produce tempered glass. For most manufactured parts, these property-enhancing operations are not required in the processing sequence.

Finally finish operations usually provide a coat on the work parts (or assembly) surface. Examples included electroplating, thin film deposition techniques, and painting. The purpose of the coating is to enhance appearance, change color, or protect the surface from corrosion, abrasion, and so forth. Finishing operations are not required on many parts; for example, plastic molding rarely require finishing. When finishing is required, it is usually the final step in the processing sequen

Processing Planning for Assemblies

The type of assembly method used for a given product depends on factors such as: (1) the anticipated production quantities; (2) complexity of the assembled product, for example, the number of distinct components; and (3) assembly processes used, for example, mechanical assembly versus welding. For a product that is to be made in relatively small quantities, assembly is usually performed on manual assembly lines. For simple products of a dozen or so components, to be made in large quantities, automated assembly systems are appropriate. In any case, there is a precedence order in which the work must be accomplished. The precedence requirements are sometimes portrayed graphically on a precedence diagram.

Process planning for assembly involves development of assembly instructions, but in more detail .For low production quantities, the entire assembly is completed at a single station. For high production on an assembly line, process planning consists of allocating work elements to the individual stations of the line, a procedure called line balancing. The assembly line routes the work unit to individual stations in the proper order as determined by the line balance solution. As in process planning for individual components, any tools and fixtures required to accomplish an assembly task must be determined, designed, built, and the workstation arrangement must be laid out.

Make or Buy Decision

An important question that arises in process planning is whether a given part should be produced in the company’s own factory or purchased from an outside vendor, and the answered to this question is known as the make or buy decision. If the company does not possess the technological equipment or expertise in the particular manufacturing processes required to made the part, then the answer is obvious: The part must be purchased because there is no internal alternative. However, in many cases, the part could either be made internally using existing equipment, or it could be purchased externally from a vendor that process similar manufacturing capability.

In our discussion of the make or buy decision, it should be recognized at the outset that nearly all manufactures buy their raw materials from supplies. A machine shop purchases its starting bar stock from a metals distributor and its sand castings from a foundry. A plastic molding plant buys its molding compound from a chemical company. A stamping press factory purchases sheet metal either fro a distributor or direct from a rolling mill. Very few companies are vertically integrated in their production operations all the way from raw materials, it seems reasonable to consider purchasing at least some of the parts that would otherwise be produced in its own plant. It is probably appropriate to ask the make or buy question for every component that is used by the company.

There are a number of factors that enter into the make or buy decision. One would think that cost is the most important factor in determining whether to produce the part or purchase it. If an outside vendor is more proficient than the company’s own plant in the manufacturing processes used to make the part, then the internal production cost is likely to be greater than the purchase price even after the vendor has included a profit. However, if the decision to purchase results in idle equipment and labor in the company’s own plant, then the apparent advantage of purchasing the part may be lost. Consider the following example make or Buy Decision.

The quoted price for a certain part is $20.00 per unit for 100 units. The part can be produced in the company’s own plant for $28.00. The components of making the part are as follows:

Unit raw material cost = $8.00 per unit

Direct labor cost =6.00 per unit

Labor overhead at 150%=9.00 per unit

Equipment fixed cost =5.00 per unit

Total =28.00 per unit

Should the component by bought or made in-house?

Solution: Although the vendor’s quote seems to favor a buy decision, let us consider the possible impact on plant operations if the quote is accepted. Equipment fixed cost of $5.00 is an allocated cost based on investment that was already made. If the equipment designed for this job becomes unutilized because of a decision to purchase the part, then the fixed cost continues even if the equipment stands idle. In the same way, the labor overhead cost of $9.00 consists of factory space, utility, and labor costs that remain even if the part is purchased. By this reasoning, a buy decision is not a good decision because it might be cost the company as much as $20.00+$5.0+$9.00=$34.00 per unit if it results in idle time on the machine that would have been used to produce the part. On the other hand, if the equipment in question can be used for the production of other parts for which the in-house costs are less than the corresponding outside quotes, then a buy decision is a good decision.

Make or buy decision are not often as straightforward as in this example. A trend in recent years, especially in the automobile industry, is for companies to stress the importance of building close relationships with parts suppliers. We turn to this issue in our later

discussion of concurrent engineering.

Computer-aided Process Planning

There is much interest by manufacturing firms in automating the task of process planning using computer-aided process planning (CAPP) systems. The shop-trained people who are familiar with the details of machining and other processes are gradually retiring, and these people will be available in the future to do process planning. An alternative way of accomplishing this function is needed, and CAPP systems are providing this alternative. CAPP is usually considered to be part of computer-aided manufacturing (CAM). However, this tends to imply that CAM is a stand-along system. In fact, a synergy results when CAM is combined with computer-aided design to create a CAD/CAM system. In such a system, CAPP becomes the direct connection between design and manufacturing. The benefits derived from computer-automated process planning include the following:

Automated process planning leads to more logical and consistent process plans than when process is done completely manually. Standard plans tend to result in lower manufacturing costs and higher product quality.

Increase productivity of process planner. The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners.

Reduced leaded time for process planned. Process planner working with a CAPP system can provide route sheets in a shorter lead time compared to manual preparation.

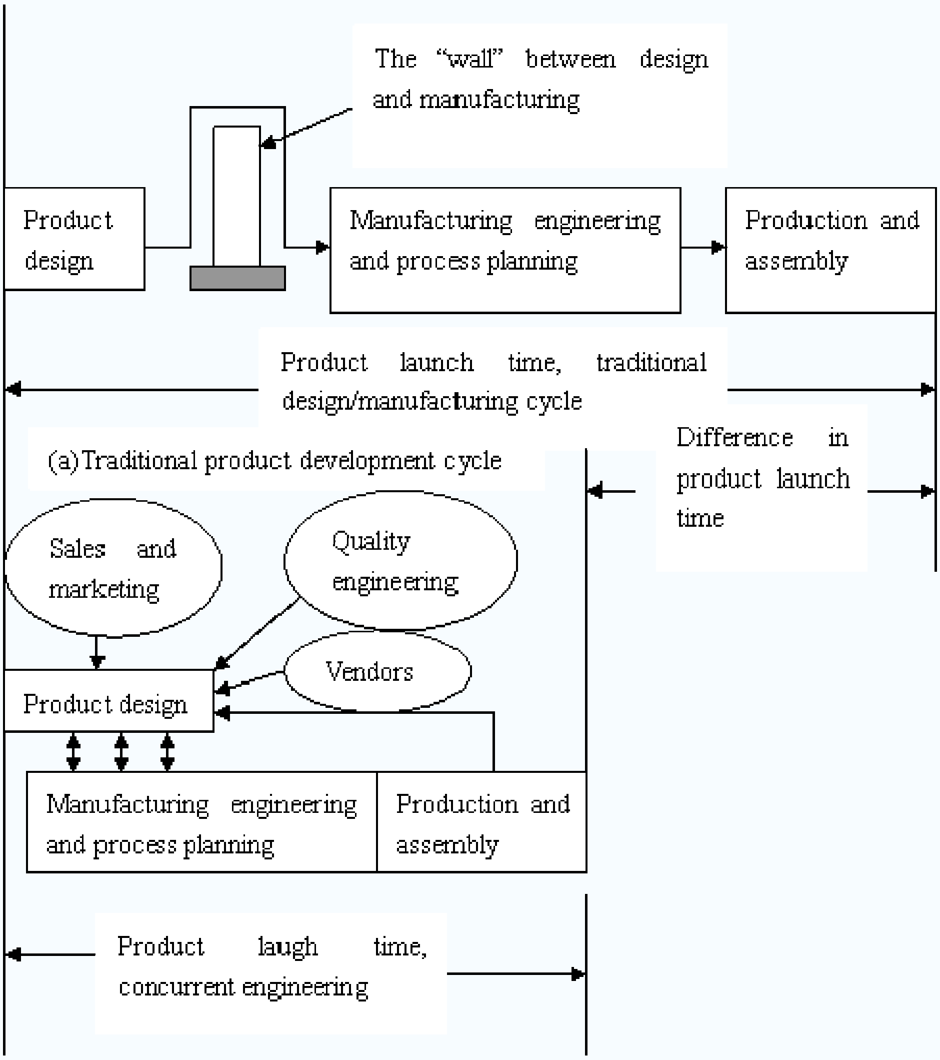
Improve legibility. Computer-prepared rout sheets are neater and easier to read than manually prepared route sheets.

The CAPP program can be interfaced with other application programs, such as cost estimating and work standards.

Computer-aided process planning systems are designed around two approaches. These approaches are called: (1) retrieval CAPP systems and (2) generative CAPP systems .Some CAPP systems combine the two approaches in what is known as semi-generative CAPP.

Concurrent Engineering and Design for Manufacturing

Concurrent engineering refers to an approach used in product development in which the functions of design engineering, manufacturing engineering, and other functions are integrated to reduce the elapsed time required to bring a new product to market. Also called simultaneous engineering, it might be thought of as the organizational counterpart to CAD/CAM technology. In the traditional approach to launching a new product, the two functions of design engineering and manufacturing engineering tend to be separated and sequential, as illustrated in Fig.(1).(a).The product design department develops the new design, sometimes without much consideration given to the manufacturing capabilities of the company, There is little opportunity for manufacturing engineers to offer advice on how t[illegible]he design might be alerted to make it more manufacturability. It is as if a wall exits between design and manufacturing. When the design engineering department completes the design, it tosses the



(b) Product development using concurrent engineering

drawings and specifications over the wall, and only then does process planning begin.

Fig. Comparison: (a) traditional product development cycle and (b) product development using concurrent engineering

By contrast, in a company that practices concurrent engineering, the manufacturing engineering department becomes involved in the product development cycle early on, providing advice on how the product and its components can be designed to facilitate manufacture and assembly. It also proceeds with early stages of manufacturing planning for the product. This concurrent engineering approach is pictured in Fig.(1).(b). In addition to manufacturing engineering, other function are also involved in the product development cycle, such as quality engineering, the manufacturing departments, field service, vendors supplying critical components, and in some cases the customer who will use the product. All if these functions can make contributions during product development to improve not only the new product’s function and performance, but also its, testability, serviceability, and maintainability. Through early involvement, as opposed to reviewing the final product design after it is too late to conveniently make any changes in the design, the duration of the product development cycle is substantially reduced.

Concurrent engineering includes several elements: (1) design for several manufacturing and assembly, (2) design for quality, (3) design for cost, and (4) design for life cycle. In addition, certain enabling technologies such as rapid prototyping, virtual prototyping, and organizational changes are required to facilitate the concurrent engineering approach in a company.

Design for Manufacturing and Assembly

It has been estimated that about 70% of the life cycle cost of a product is determined by basic decisions made during product design. These design decisions include the material of each part, part geometry, tolerances, surface finish, how parts are organized into subassemblies, and the assembly methods to be used. Once these decisions are made, the ability to reduce the manufacturing cost of the product is limited. For example, if the product designer decides that apart is to be made of an aluminum sand casting but which processes features that can be achieved only by machining(such as threaded holes and close tolerances), the manufacturing engineer has no alternative expect to plan a process sequence that starts with sand casting followed by the sequence of machining operations needed to achieve the specified features . In this example, a better decision might be to use a plastic molded part that can be made in a single step. It is important for the manufacturing engineer to be given the opportunity to advice the de sign engineer as the product design is evolving, to favorably influence the manufacturability of the product.

Term used to describe such attempts to favorably influence the manufacturability of a new product are design for manufacturing (DFM) and design for assembly(DFA). Of course, DFM and DFA are inextricably linked, so let us use the term design for manufacturing and assembly (DFM/A). Design for manufacturing and assembly involves the systematic consideration of manufacturability and assimilability in the development of a new product design. This includes: (1) organizational changes and (2) design principle and guidelines.

.Organizational Changes in DFM/A. Effective implementation of DFM/A involves making changes in a company’s organization structure, either formally or informally, so that closer interaction and better communication occurs between design and manufacturing personnel. This can be accomplished in several ways: (1)by creating project teams consisting of product designers, manufacturing engineers, and other specialties (e.g. quality engineers, material scientists) to develop the new product design; (2) by requiring design engineers to spend some career time in manufacturing to witness first-hand how manufacturability and are impacted by a product’s design; and (3)by assigning manufacturing engineers to the product design department on either a temporary or full-time basis to serve as reducibility consultants.

DFM/A also relies on the use of design principles and guidelines for how to design a given product to maximize. Some of these are universal design guidelines that can be applied to nearly any product design situation. There are design principles that apply to specific processes, and for example, the use of drafts or tapers in caste and molded parts to facilitate removal of the part from the mold. We leave these more process-specific guidelines to texts on manufacturing processes.

The guidelines sometimes conflict with one another. One of the guidelines is to “simplify part geometry, avoid unnecessary features”. But another guideline in the same table states that “special geometric features must sometimes be added to components” to design the product for foolproof assembly. And it may also be desirable to combine features of several assembled parts into one component to minimize the number of parts in the product. In these instances, design for part manufacture is in conflict with design for assembly, and a suitable compromise must be found between the opposing sides of the conflict.

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