# 机械原理

## 平面机构结构分析

### 自由度计算

#### 计算公式



其中为自由度，为低副个数，为高副个数，为活动构件个数

#### 低副

常见的低副为移动副与转动副

|  |  |
| --- | --- |
| 移动副 |  |
| 转动副 |  |

#### 固定构件

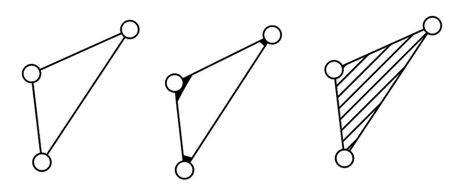
构件分为活动构件和固定构件（机架）。图片包含 图示

AI 生成的内容可能不正确。常见的机架：

手机屏幕截图

AI 生成的内容可能不正确。\*该图与上图定块十分类似，但是下面的图滑块是可以运动的，而上面图的定块是固定构建不可运动。

#### 活动构件

形状

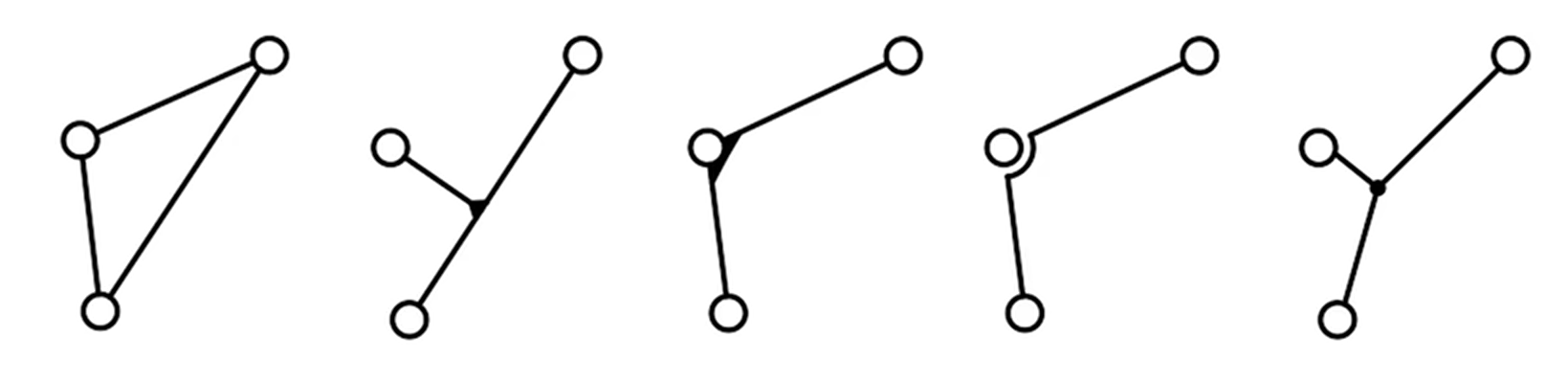
AI 生成的内容可能不正确。图表, 箱线图

AI 生成的内容可能不正确。常见的活动构件：

形状, 矩形

AI 生成的内容可能不正确。图片包含 图标

AI 生成的内容可能不正确。



线条连续即为同一构件。

上图所有三角形等价。其中拐角的阴影代表焊接，实心的阴影代表桁架。

#### 高副

常见的高副为齿轮副，凸轮副，圆弧高副和滚子高副

##### 齿轮

图示, 工程绘图

AI 生成的内容可能不正确。图示, 工程绘图

AI 生成的内容可能不正确。

图示, 工程绘图

AI 生成的内容可能不正确。

两齿轮接触点为高副。

##### 凸轮

形状, 圆圈

AI 生成的内容可能不正确。图示

AI 生成的内容可能不正确。

左图1虽然线条连续但是明显是分开的（否则转起来断掉了）所以不能认为是一个构件。

##### 图示 AI 生成的内容可能不正确。圆弧和滚子

#### 基础机构

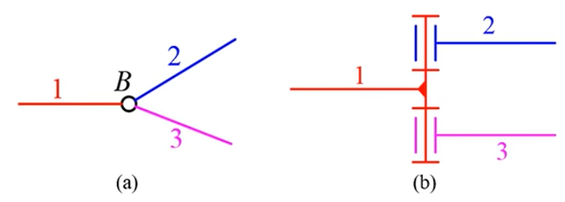
#### 图示 AI 生成的内容可能不正确。机构的运动

机构原动件数目等于机构的自由度数目且自由度大于0时具有确定运动。

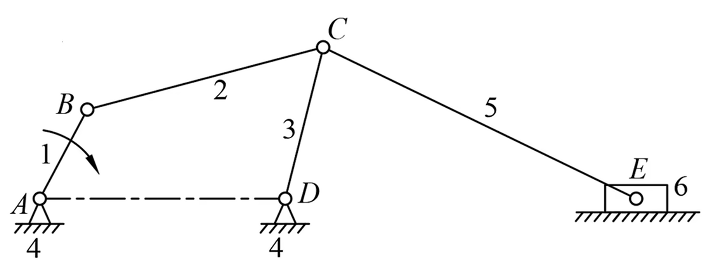
如果机构的原动件数小于机构的自由度，机构的运动将不确定；如果原动件数大于机构的自由度，将导致机构中最薄弱环节的损坏。

因此题目中**自由度大部分为1或2**。

#### 复合铰链



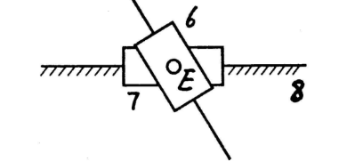
*C*



图中的C点看似是一个转动副，实际上画成俯视图为两个转动副。

当构件在同一点形成转动副时，转动副的数目应为。注意，这里的是包括机架（固定构件）的

注意：右图不是复合铰链，因为转动副只连接了两个构件



#### 局部自由度

图示

AI 生成的内容可能不正确。不影响其他构件运动，仅与其自身的局部运动有关的自由度称为局部自由度。

局部自由度的表现形式一般为滚子构件。在计算机构自由度时应将局部自由度去除，即将滚子和与其通过转动副连接的一个构件焊在一起再进行计算。

#### 虚约束

在机构中不起独立限制作用的重复约束称为虚约束。

##### 距离不变虚约束

图示

AI 生成的内容可能不正确。

##### 移动副导路平行虚约束

手机屏幕截图

AI 生成的内容可能不正确。

此类虚约束计算自由度时需要去掉一个移动副。

##### 构件重复虚约束

图示

AI 生成的内容可能不正确。图示, 工程绘图

AI 生成的内容可能不正确。

##### 图示 AI 生成的内容可能不正确。对称虚约束

图中红色部分可以去除，效果不变。

##### 高副公法线重合虚约束

图示

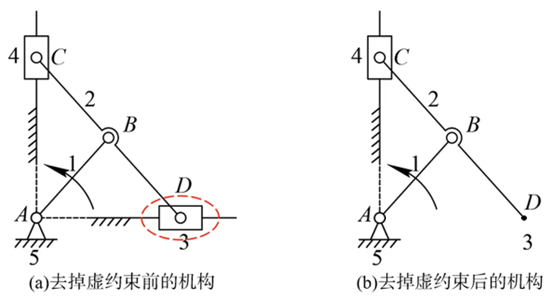
AI 生成的内容可能不正确。

形状

AI 生成的内容可能不正确。

若高副公法线重合，保留两处高副中的一处即可。

##### 轨迹重合虚约束



去掉移动副之后仍与先前轨迹重合，故为轨迹重合虚约束。

图表, 折线图

AI 生成的内容可能不正确。

![图表, 折线图

AI 生成的内容可能不正确。](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAXEAAAKTCAYAAADv4ziwAAAAAXNSR0IArs4c6QAAAARnQU1BAACxjwv8YQUAAAAJcEhZcwAADsMAAA7DAcdvqGQAAFwYSURBVHhe7d2Hd1X1uj76399zGfeOe8/ZSiCNJKQTQhqL3hKQDuk9lFCCFKWTuvrsc60ki6YUC7oEFUWXYu9b3batIgRs+7njO+dayWIBbguwcft8xnhHCAQy8Zzz8J53fsv/+T9ERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERERET032Do8MEFQ0cOXhw6fBDDRw5i6Mg+mMO7oA9uhxrsgmxusT4OH9uDU2dcOHXGefHkE84FiX8OERHdZYOH9xcOhg6G/Oom+NVO+JQNcEttGPA1wulvgluyy6M0w6e1Qw10WuGuDW4PqYPbCxP/PCIiuktEgKvB9pBX7oBXboFqroOst8ErN8KrNELSWyAbrVACbVaJz/1aC5y+RrildgY5EdF/imq2FypGS8jtb4ZPaYEWbIdqtkIxmiHrzfBrTZBFiEdLMVqtn7d/vQVeuRmy1gmv0h6S1HYGORHR3WIHeHPIK7daXbcIaMVogU9tsEr8nNvfCJevEQOeBvS76+DyNcCrNEAxm6AF26CabZD1DivIJY1BTkR0V+h62ziXd63c766HTxVddZMV4mJM4pVF990O1WiNeOWGsCiXz/4oSgu2RdSA6MqbYX9sh09ph0/eBEntCHmlTQxyIqI7STHXJanGunCfe+3oeESMU/zqOgwffQjDR3eFho885Bg6ujPJ6W0YLa/SkCSrrQ5JawlZ4xSlHorRBsXogNvXDlndBq/UKUt617jE70lERLeJanQ4NKMj4vJVQ9LsLtwjtcIc3GGNRQaP7frFblpSWwoVoz3kkeohaaKTb4WkroNqdEGS14UVsysp8fcQEdFtIEYpbl+9rJnr4JPrIavNkJQWKNomqwP/dwEeI6tNDllvj/jkRsjiBajaBkleD8XoYogTEd0psVGKX2mBpNTDLzfC52+BMbgjIkYoiV9/K16lJUlSm8OK1gpJaYCstsLnFy9HGeJERHdMLMQ9/gZISp0V4pIiuuiWsJiBJ379rYgQl9XGsBFYB79cD0lpgl9u4TiFiOhOEiFuBFutEJc1O3xVfR0kuTEsgjnx62/l6NGuJEluCKtGG/yy+MegAX6xskVpY4gTEd0pdie+PuyVGqEajVD05ug8+7eF+JHjOxyy1hJRdDGWqYuOZhogqW0RWW761WMZIiL6DWIh7ldaYQZbIatiDNIUDfGGXxXix45tLzx67MGQGKWIebik1kHWxHhGvChth19qDElSy696QUpERL+Brm8cpxrrZc3cACNgh7gYqWh6Z0SsAU/8+kR2gG8PDQ5vgsdfawe3Fleq6MzbISnNDHIiojtBNdY7NGNDRIw/xDjFHom0QVJaQ7La4ZD0tptu1okF+NHjD0Y7eLsDF+Gt6OLPEh/FcsMW+CXx5zHIiYhuu9hIpd+5ForWYgW5pLRCNzZB1tojsrpeFmGuKC1JR4/utErMwO0A3wHxMlOMUezgjpUI8Lroj0V3L2btHVaQixm5mLfr3MlJRPTHiZGKT6qX3V7RTYuwbYKitUPR1lul6hugGxsjit4RlpXWsCS3ho8e2xExgxutLtv6enHeyk1DXHwUoxWxdFGEeRsktT0iK41hSW2VDWObwzS7kiR9IwOdiOj3Us0NhZLUHpLkDnh8jVC0DujGBmu5oSpOJhQrVhSxkUeMWpqtl5/WC1BFhHczVCMxxGNBfn1HLgLfJzXC42uyRiyqtjFiGNvCqr5BVlUelkVE9LuZ5qZCv9Qc8ksdEGFumJ1WxYe5boozUdogdmbGRi923SzExzpy1WiIlljGKD7as3fxj4Oqi+/zIFRtQ0hVNzDIiYh+LxHkhtEZ8ksb4JfEKGUTFK0TirYBiiaCXPxcB1RdnFIoRi/R8ctokNshHR/iqiFKBHl8iZ+zu3PxD4Kqb4RhbrOCfHBwP4OciOj3EkGuaptCTtd6DDg74PNtgqxshiSLYF8H0an75VZrfh4bq4jt+tbmHnEc7a1C3Ky5saxAFxuNRHe/Hqq2FYOD+0LB4B7H0NA+zsmJiH4PSdpQ6JPWyz5pfdgnrQtL8vqwLG+ySvxY0deFZaU5Wo1hv9wQsQ+/EqcYivCOdeT2OEXWqqHoa6GaiVUN1ai1xyxWR77B+gdjcHBvRNU3yezKiYh+J0naOM7rXZckSlE2JXkV+6NV5roksUzQroYksWxQkhtlzWiL6Gab/RLT2vAjArzWCnFZWw3FWAPFWDVaqrnGCnNFr4nOysWMfAMUdQsGh/ZB/H8EDHIiortAkhrGiXPFFa0xJMLY7sjF5p9bh7hdK60uXdFrrQ4+FuSqvhnDw3aQm+Z2BjkR0d0gqQ2FmtEaEksJ3b4a+KQaSGpNNMjXWGEeH+iyvgKytgqKLkYrsRm5WP3Sbr1YHRzabQU5lyASEd0lktRQKKn1spiVm8H11o5OvyyC3O7KJVWEuQjxNZD1lZB10ZGL0UpsRi5GK+JYXHvTkRl4EIODu0PB4EOOoaHd3BxERHSn6UMbx8lqvUOS62UjuD4idneK9eH2rFyEuQj1tVYXbof42IxcD9RCD9RDN5usrlwsaxTLHFWtM6IbXWFV75AlriknIrrzRJgbwfUOI7g+JEYk9tpysYoltpuzOtqF26UHRIhXR6sOutkI3WyGeGFqbzraBN0Qa8rbQ7K63sGunIjoLjDF1n61OSR2gIo7OO1LmUWI10bXjYslh7EQj5UI8loYwQaYg83Wcbn2gVvtkJWN0I0HI7K6QTbNrezKiYjuNEltKZTUJlmsL5fUhoi9iiW6NT8a5NeHuB3kRlAEeT2MoHjpKeblLdERi9iyvx2K2hkaHhbz8l3syomI7iSxFNEc2pQUDHY6goObrBuBxLpy3Wywxyejo5SxIDeCNVaQ64Eae15ujVhaoBvroGhiy/6DGBraHTGMLTLDnIjoLjEHNxVqRksoOLTJDmWz0Rqd2C82bwxz+3MR5GJWHj1IK3psrmFuxfDwbivMdWOrPDi4hyMWIqI7zTTbC3WjRQ4OdkZ3ezZYAW0ERVcuAjsxxKvtpYjW2St2kNsbhNZZF1noRheCg3sQHNwdMhnkRER33tCQuOuz1RqvmEFx3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如上二图所示。

### 高副低代

在含有高副的机构中，将高副虚拟地用低副替代称为高副低代。机构中常见的

几类高副低代方法分述如下。

#### 曲面高副接触

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1、杆2分别为原来的构件1与构件2，增加一个杆4替换原来的高副 | | |

#### 凸轮

##### 尖底凸轮

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1为原来的凸轮1，增加一个杆4替换原来的高副 | | |

##### 滚子凸轮

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1为原来的凸轮1，杆4为原来的滚子 | | |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1为原来的凸轮1，杆2为原来的滚子 | | |

##### 平底凸轮

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1为原来的凸轮1，杆4为原来的滚子 | | |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后杆1为原来的凸轮1，杆2为原来的滚子 | | |

#### 滚子

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 代换后构件3为原来的滚子3 | | |

图示

AI 生成的内容可能不正确。滚子在曲面上运动时类似曲面高副接触的情况。

#### 齿轮

图示

AI 生成的内容可能不正确。

雷达图

AI 生成的内容可能不正确。

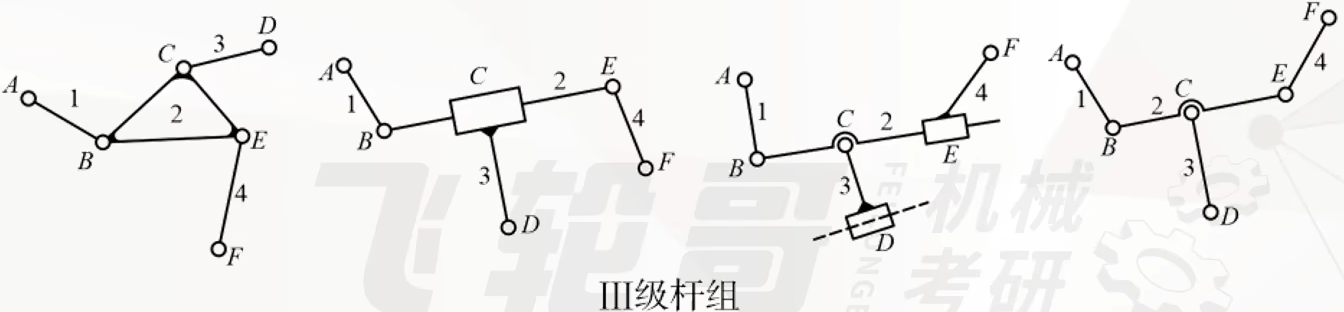
此处两个红色角都为直角

### 杆组拆分

#### 基本杆组

自由度为零且不能再拆分的构件系统称为基本杆组。最简单的基本杆组由两个构件和三个运动副组成，称为Ⅱ级杆组。图示

AI 生成的内容可能不正确。

四个构件和六个运动副构成的基本杆组为III级组

机构的级别即为机构中基本杆组的最高级别。

#### 三角架拆分

#### 基本步骤

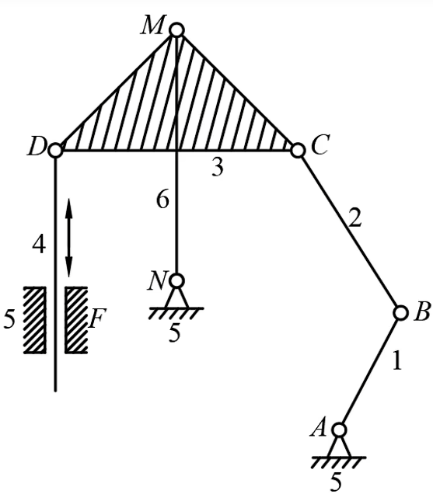
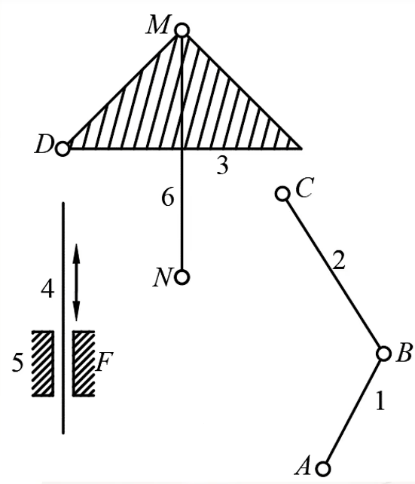
(1) 首先去除机构中的虚约束并对局部自由度进行处理

(2) 计算机构的自由度并确定原动件;

(3) 然后对机构进行高副低代;

(4) 拆分时先将原动件拆下，之后从原动件部分开始试拆杆组，首先考虑II级组，拆下的杆组是自由度为零的基本杆组。

注：机构中仅原动件的机架需要保留。



图示, 示意图

AI 生成的内容可能不正确。图示

AI 生成的内容可能不正确。

注意：该题中E点为复合铰链，拆分时要记为两个转动副

### 机构运动简图绘制

#### 基本步骤

1. 找出图中的机架
2. 找到与机架直接相连的构件1、2，判定其与机架通过转动副还是移动副连接
3. 抽象、简化构建1、2，画出相应的运动副
4. 找到跟构件1、2直接相连的构件3、4，并重复上述步骤2。

#### 例题：唧筒机构

如图1，先找到机架为4，其与1通过转动副连接，与3通过移动副连接且始终与3 的方向位于同一直线，可抽象为图2。最后再来看与1、3相连的构件2.可知2与1、3都通过转动副连接，最终抽象为图3。

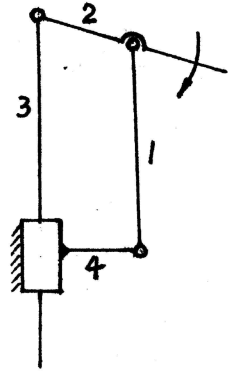


图3

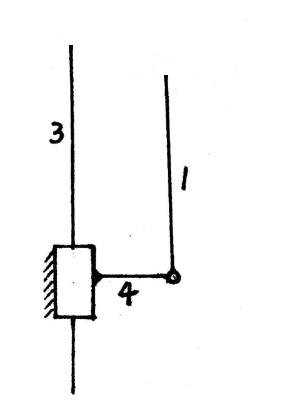


图2

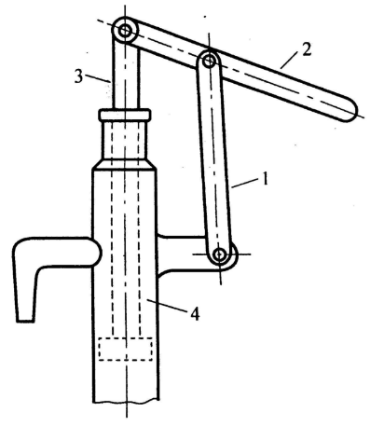
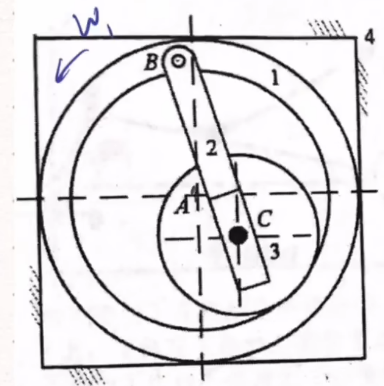


图1

#### 图示, 工程绘图 AI 生成的内容可能不正确。例题：偏心油泵

右图偏心油泵中间部分的运动形式与下图机构相同

（当A点是机架而C点不是）

1. 圆球球心绕A运动
2. 直杆所在直线上固定一点为球心

A点为机架，圆AC（原图的AB）可以简化为杆，通过转动副与直杆相连，直杆通过移动副与构件3相连，3通过转动副与机架相连。

得到最终答案（右图）。图示

AI 生成的内容可能不正确。

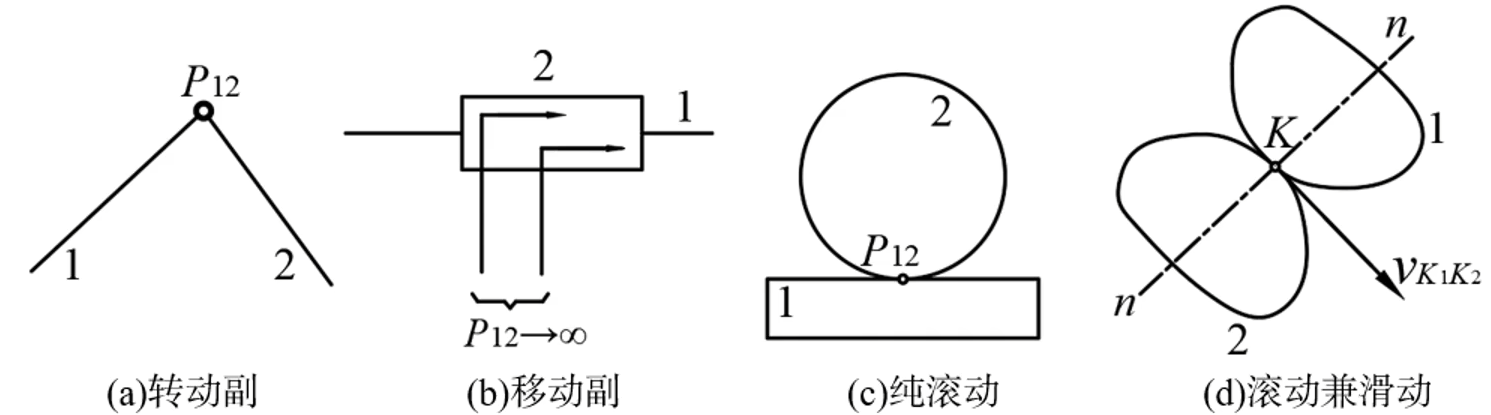
## 平面机构运动分析

### 速度瞬心法

#### 速度瞬心

相对速度瞬心是两构件上相对速度为0的重合点，或者说是瞬时绝对速度相同的重合点。绝对速度瞬心就是构件上绝对速度为0的点。

构件和构件的相对速度瞬心一般用符号表示



对于直接接触的形成转动副的二构件，由定义可知其速度瞬心为转动副。如图(a)。

对于移动副，其速度瞬心在垂直于移动副导路的无穷远处。移动副的瞬心可以进行平移，效果相同。

对于纯滚动的高副，两构件的接触点即为两构件的瞬心。

对于滚动兼滑动的高副，瞬心在两构件接触点的公法线上，但不能确定其具体位置。

一般默认高副为滚动兼滑动的。齿轮一般为纯滚动，凸轮一般为滚动兼滑动。

#### 三心定理

作平面平行运动的三个构件共有三个瞬心，它们位于同直线上。

图示

AI 生成的内容可能不正确。图表, 图示, 折线图

AI 生成的内容可能不正确。

#### 图片包含 灯光, 线, 挂, 交通 AI 生成的内容可能不正确。瞬心法求解速度和角速度

已知，求

瞬心的定义是两构件上速度相同的点。



即可求出。

从而我们可以得到一个普遍性的公式

对于任意两活动构件1,2,以及机架3

有



图示

AI 生成的内容可能不正确。已知，求图示凸轮机构中构件2的运动速度

显然

### 相对运动图解法（矢量图解法）

#### 同一构件

在理论力学中我们学过，对于同一刚体（构件）上两点，其速度的关系为



加速度的关系为



#### 移动副两构件上瞬时重合点

图示

AI 生成的内容可能不正确。在理论力学中我们学过，绝对运动是相对运动和牵连运动的矢量和，体现在移动副两构件上瞬时重合点间的运动关系即为



加速度的关系为



其中为科氏加速度



其中为动系绕定轴转动的角速度矢量（这里就是杆的角速度矢量）。

也可以这么说：的大小是，方向为沿着（顺/逆时针）的方向旋转。

当两构件通过移动副连接时，则这两个构件的角速度和角加速度大小和方向均相同。

#### 例题1（展示一般求解过程）

图示

AI 生成的内容可能不正确。已知一机构如图所示，已知原动件等角速度转动且转动角速度为，试求的大小与方向。

经过测量可以得出

（假设是这样）

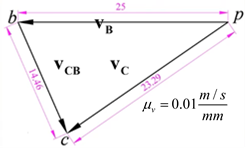
也即





|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| 方向 |  |  |  |
| 大小 |  |  |  |

据此可以画出速度矢量图（右图）

点为画图的起点，也称为**极点，**由出发的指向的有向线段即为点的速度，以此类推。

由图可知



可以求得

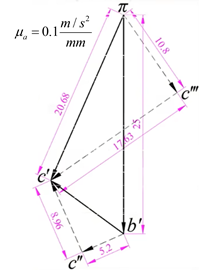
，方向为顺时针

，方向为逆时针



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| 方向 |  |  |  |  |  |
| 大小 |  |  |  |  |  |

可以求得



据此可以画出加速度矢量图（右图）

（这里认为两点都是求的过程量因此这样标）

量出



方向都为逆时针

#### 图示 AI 生成的内容可能不正确。速度影像法

机构中某个构件上的点形成的图形，与速度和加速度矢量图中的图形应该是对应相似的。

如果上题中构件2不是杆而是如右图所示的三角形BCE，那么会有速度三角形中

图示

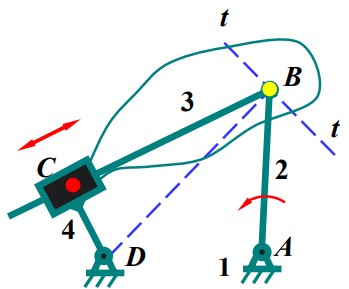
AI 生成的内容可能不正确。

图示

AI 生成的内容可能不正确。不妨看看右图，对于相似三角形，点有四种可能。其中从对应就可以排除掉，速度影像法还要求顺时针读顶点的顺序一样，原图中顺时针读为，速度矢量图中点若在则顺序为，与上述不符。而则满足题意。从而得到了正确的速度矢量图。

对线段上的点也适用。某个构件上某个点在速度矢量图中有，可以认为是三角形的极限情况。

#### 文本 AI 生成的内容可能不正确。重合点的选取



#### 卡通人物 AI 生成的内容可能不正确。例题2

已知各杆长，构件1逆时针匀速转动，其角速度已知。求此时构件5的速度。

思路：求构件5的速度就是求E的速度，找到构件3的绝对瞬心（），从而问题转化为求解构件3的角速度。图片包含 图示

AI 生成的内容可能不正确。

## 平面机构力分析