# 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

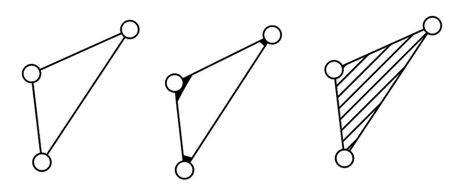
构件分为活动构件和固定构件（机架）。图片包含 图示

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

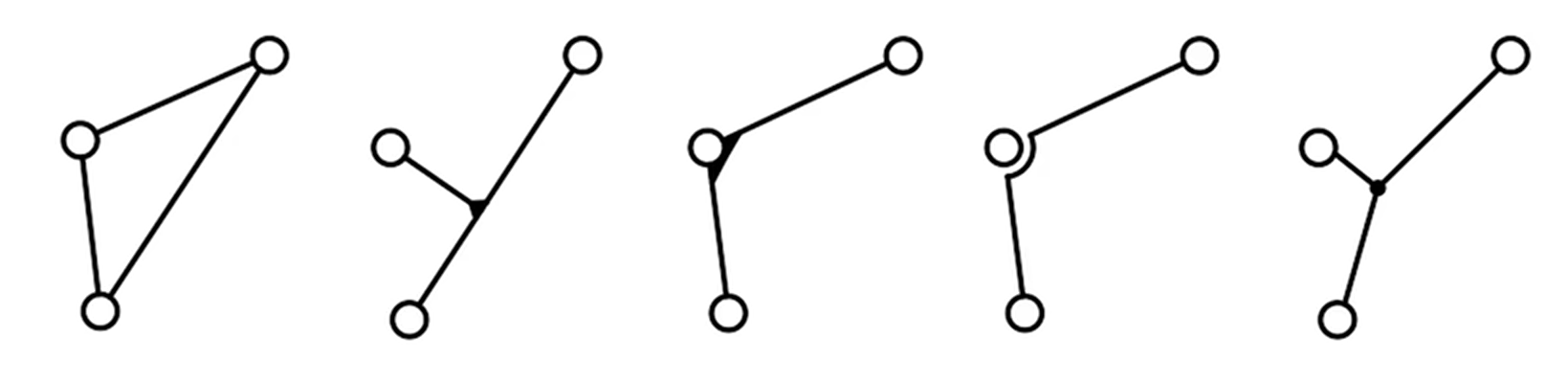
AI 生成的内容可能不正确。图表, 箱线图

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

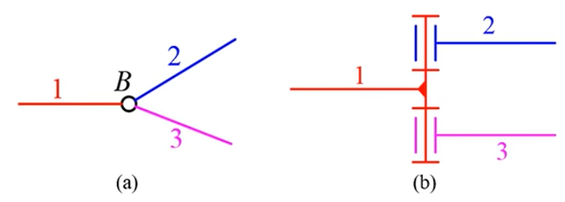
#### 图示 AI 生成的内容可能不正确。机构的运动

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。

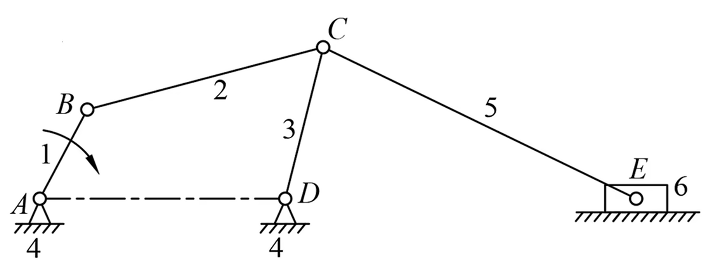
如果机构的原动件数小于机构的自由度，机构的运动将不确定；如果原动件数大于机构的自由度，将导致机构中最薄弱环节的损坏。

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

#### 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

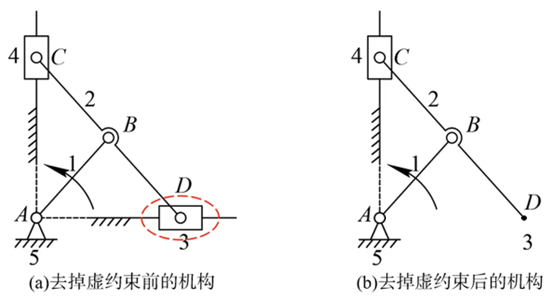
AI 生成的内容可能不正确。

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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BbiohMXR89GQ/yXZuLXhXg0VMV4Q9y4U5qOyxXp+HzWJLy9IAMXVxfgjY2zra78fXcd3pOa8Ja/EW9IjXjDV4+3fPX4wNeIj72N+GKgDp/vXo5POmbjw5WF+GheBj6fnoLvYjf6iFn4LQM84URDUdbYJfoStHgSvinLwesixCtn45mFMxjiZCvp67O68owD+8Ppe0QdGK2M3QfD8wc8Vk2zLjZm9033li8nJyddzksJf5mdhB/zfyHEY+OT6yoW4rHQHAvya+Xp+EdFCt6ekYLXKjPxRm0xPtw4Fx89WIkPHqzEu9sr8X70xx9vXYRPN87Dp80OfLSiEB/Nz8QnjhR8WToRV4on4l9iSaH1MvNWIS4CPOPGII+9/BRH1kZD/I3yApxdOAuvlhcwxGmM6MpLnD1J6bsPjNZ8p3e0qrzeJHbfdC/6R15y0pfZSeEvsifgh3wRltEXm/EhfkN4x4d4LETHVqtg2iSgdBK+L5+Er8vT8HF5Mt6fkYIP5mXgg6ocfLAkF+8tzsH7i3Oszz+uzMEn8zLxyYw0fFo2Ef8sS8ZIaYo1nrGXE8YFeOKqFOtz8b3F+vboGvfEEmvfiyfha9GJVxTg7KKZeGV6UfhsFV9sEtGfnAjxz3JSwp/lpuCKmInHQtzanfkLIW51vnEl1piLEr9frDUvyQRKM/FTWSZGyibh27I0fFWWis/LU/FZeSo+LUvBP8pS8FlZivXz4tevlIsr1NLxU5n9j8ANN9tHO+rrAzoa0rHvH1/iWaznybKe6cvyXFysKER40Uw8P31q+CxXpxDRn91HeelJH+Snhz/MT8dX+aLzFVvvM28M7VgwFolNQVnR3Z1xNS1nrEqygZLJQOlk/FyShR9LsvB9aSaulmRgpCQDV0ozcLnU/ig+v1aSge9LMvBjSSZ+KsnEzyWZ+Jf4hyBWsTAeLdFZx0p8LkJaPENiZUefSawvz8Fn5YWiA8dTlbPsEGcnTkR/dm8WTbZC/M2pOfhgSha+LsnFpZIcfFc8ebQuF0/GlWnZVo2U5Fp1pSQXV0vzcS1a35cVWBcR25WPa+V5GCnNtassF1fi6rKo8jxcEV8jPpbZX5NY4nb6azdUTrSy436ci+/L8kbrh9HKxw9lBRgpLcDlskJ8OL0Y56cX4/GqOVaIP8YQJ6I/OxHib0zNDj9ZkIUzk1PwUmEGIgWTcLEwA6+JKsjA6wUZeCNabxZmWvVWYSbenpL1q+qtKVl4s+jflPiahBK/7/o/S3zPDLwzJQPvXleZeHdK1lgVZuG9wiy8H633CrPx/pQ8nC/KwyNT8hCaNwOPV86WT1XN43sqIvpze6sod9ybRdk9T+ZnhmN1oWBS+LWCSeHX88fqjYIMq94syAi/XZj5u+rNwszwG0X/pqJfl/h7Rb1TOCmhMsLvWD9/83q3IDv8fmFe+IPpU8Oi8xYVmucIiwA/vWg2V4oR0X+HM7kZ487kTU56KS/9uroYV2/+UhVNvsMlvodd7/27ypt8Q300vcgqMT4RxQ6ciIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiIiI6K76/wHeE4h4nu6VpwAAAABJRU5ErkJggg==)

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