实验报告：波尔共振仪实验

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1. **摘要**

**实验简介&意义：**振动是自然界的基本运动形式之一，简谐振动是最简单最基本的振动。而借助波尔共振仪，则可以研究阻尼振动及受迫振动的基本规律。

**实验目的：**

1. 学习测量振动系统基本参量的方法。
2. 观察共振现象，研究波尔共振仪摆轮受迫振动的幅频特性和相频特性。
3. 观测不同粘滞阻尼对受迫振动的影响。

**关键词：波尔共振仪，阻尼振动，受迫振动**

**二、实验原理**

共振仪的摆轮与弹簧组成了一个扭转振动系统，假定弹簧刚度系数和摆轮转动惯量均不变，并认为只存在与角速度成正比的粘滞阻尼这一种阻尼作用，阻尼为零时，振动系统满足运动方程

（1）

如果有粘滞阻尼力矩，则满足运动方程

（2）

当阻尼比0ζ<1时，系统进行振幅不断衰减的振动，解方程可得出阻尼振动周期为

Td=T0/

当共振仪电机带动偏心轮转动时，可以证明，弹簧支座一阶近似下作简谐角振动，满足方程

α(t)=αmcos，αm为摇杆摆幅。

这时摆轮的运动方程为

（3）

等效于受周期性外力矩作用的受迫振动。稳态解的振幅和相位差分别为

(4)

(5)

**三、实验仪器&实验步骤**

**实验仪器：**波耳共振仪，包括：

1. 振动系统：A&B
2. 激振装置：电机&E、M
3. 相位角测量装置：F&闪光灯
4. 电磁阻尼系统：K

**实验步骤：**

1. 最小阻尼时测定摆轮振动周期Tdj与振幅的关系

将阻尼开关置于0档，，周期选择档置于10位置，每按一次复位按钮，读取显示的10个周期平均值并记录10个周期中首尾两次的振幅，求出平均值，在30~150°范围内测量6组数据。

1. 测量最小阻尼比

周期选择置于1位置，拨动摆轮至起始角为120-180°，松开使其自由摆动，对每K个周期读取一次振幅值，由等间隔振幅值求对数缩减，进而求出阻尼比。

1. 测量其他档位阻尼比、测定受迫振动的幅频特性和相频特性曲线

选择阻尼档为3、4、5档之一，用前述方法测得阻尼比，之后保持阻尼档位不变，开启电机开关，调节强迫激励周期旋钮，测定幅频特性和相频特性。

**四、数据处理**

1. **最小阻尼振动周期与振幅的关系**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 初始振幅 | 94 | 92 | 86 | 69 | 60 | 52 | 45 | 37 | 30 |
| 末振幅 | 93 | 90 | 81 | 64 | 55 | 47 | 38 | 32 | 26 |
| 周期 | 1.547 | 1.542 | 1.537 | 1.532 | 1.53 | 1.528 | 1.526 | 1.525 | 1.523 |
| 频率 | 4.061528964 | 4.074699 | 4.087954 | 4.101296 | 4.106657 | 4.112032 | 4.117422 | 4.120122 | 4.125532 |
| 平均振幅 | 93.5 | 91 | 83.5 | 66.5 | 57.5 | 49.5 | 41.5 | 34.5 | 28 |

1. **测量最小阻尼比**

间隔周期K=5；

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 振幅θ | 152 | 145 | 135 | 130 | 124 | 119 | 113 | 107 | 101 | 95 | 91 |
| 时间t | 7.66 | 15.32 | 22.98 | 30.64 | 38.3 | 45.96 | 53.62 | 61.28 | 68.94 | 76.6 | 84.26 |
| yj = ln θj | 5.023880521 | 4.976734 | 4.905275 | 4.867534 | 4.820282 | 4.779123 | 4.727388 | 4.672829 | 4.615121 | 4.553877 | 4.51086 |
| xj | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

由LINEST函数求得:lnθj-xj函数的斜率，由相关公式：

Δ=-b1/K;

ς=Δ/(Δ^2+4\*PI^2)

UΔ=tp(v)sb1/(K\*n^1/2)

Q=

由练习一中数据：

|  |  |
| --- | --- |
| 平均周期T | 1.532222222 |
| 固有角频率ω0ωj | 4.1007 |

可以求得

|  |  |
| --- | --- |
| 直线斜率b1 | -0.050819109 |
| 对数缩减Δ | 0.010163822 |
| 阻尼比ς | 0.000257452 |
| 不确定度UΔ | 0.000109818 |
| 不确定度Uς | 0.103945791 |
| 时间常数τ | 947.2090109 |
| 品质因素Q | 1942.109995 |

由练习一所得，求解，并得出和的关系，结果如下

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 平均振幅 | 93.5 | 91 | 83.5 | 66.5 | 57.5 | 49.5 | 41.5 | 34.5 | 28 |
| 固有角频率 | 4.061529099 | 4.074699 | 4.087954 | 4.101296 | 4.106657 | 4.112032 | 4.117422 | 4.120122 | 4.125532 |

1. **其他阻尼档位的阻尼比、幅频特性和相频特性曲线**
2. **阻尼挡位：3；K=2**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 振幅θ | 166 | 138 | 122 | 107 | 94 | 83 | 73 | 64 | 57 | 50 | 44 | 39 | 35 | 31 | 27 | 23 | 20 | 18 | 15 | 13 |
| 时间t | 7.66 | 15.32 | 22.98 | 30.64 | 38.3 | 45.96 | 53.62 | 61.28 | 68.94 | 76.6 | 84.26 | 91.92 | 99.58 | 107.24 | 114.9 | 122.56 | 130.22 | 137.88 | 145.54 | 153.2 |
| Yj = lnθj | 5.111987788 | 4.927254 | 4.804021 | 4.672829 | 4.543295 | 4.418841 | 4.290459 | 4.158883 | 4.043051 | 3.912023 | 3.78419 | 3.663562 | 3.555348 | 3.433987 | 3.295837 | 3.135494 | 2.995732 | 2.890372 | 2.70805 | 2.564949 |
| xj | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |

与练习二同理求得：

|  |  |
| --- | --- |
| 直线斜率b1 | -0.12969873 |
| 对数缩减Δ | 0.064849364 |
| 阻尼比ς | 0.010320547 |
| 不确定度UΔ | 0.000127867 |
| 不确定度Uς | 0.044402066 |
| 时间常数τ | 23.62867031 |
| 品质因素Q | 48.44704417 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 周期 | 1.422 | 1.453 | 1.479 | 1.498 | 1.513 | 1.516 | 1.524 | 1.528 | 1.53 | 1.535 | 1.554 | 1.58 | 1.62 | 1.642 |  |
| 频率 | 4.418555068 | 4.324284 | 4.248266 | 4.194383 | 4.152799 | 4.144581 | 4.122825 | 4.112032 | 4.106657 | 4.09328 | 4.043234 | 3.9767 | 3.878509 | 3.826544 |  |
| 振幅θ | 27 | 33 | 47 | 63 | 83 | 83 | 95 | 110 | 104 | 91 | 70 | 47 | 33 | 28 |  |
| 周期 | 1.422 | 1.455 | 1.479 | 1.499 | 1.515 | 1.516 | 1.527 | 1.528 | 1.53 | 1.543 | 1.553 | 1.561 | 1.58 | 1.619 | 1.643 |
| 频率 | 4.418555068 | 4.31834 | 4.248266 | 4.191585 | 4.147317 | 4.144581 | 4.114725 | 4.112032 | 4.106657 | 4.072058 | 4.045837 | 4.025103 | 3.9767 | 3.880905 | 3.824215 |
| 相位差 | 167 | 164 | 155 | 138 | 128 | 124 | 114 | 110 | 100 | 93 | 77 | 50 | 28 | 24 | 14 |
| 求得ω0（Hz） | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 | 4.115 |
| 相位差计算值(弧度制) | -0.14388115 | -0.21072 | -0.31311 | -0.51022 | -0.9222 | -0.96407 | 1.564324 | 1.501005 | 1.376627 | 0.77723 | 0.546895 | 0.437065 | 0.293135 | 0.26882 | 0.139783 |
| 相位差计算值(角度制) | 171.7562175 | 167.9268 | 162.0603 | 150.7664 | 127.1618 | 124.7627 | 89.62919 | 86.00124 | 78.87491 | 44.53201 | 31.33479 | 25.04199 | 16.79538 | 15.40225 | 8.008965 |
| 相位差偏差 | -4.75621753 | -3.92677 | -7.06027 | -12.7664 | 0.838231 | -0.7627 | 24.37081 | 23.99876 | 21.12509 | 48.46799 | 45.66521 | 24.95801 | 11.20462 | 8.597754 | 5.991035 |
| 振幅计算值 | 29.11211628 | 43.45251 | 65.04466 | 104.5253 | 172.3869 | 177.8228 | 218.0217 | 217.6379 | 214.3495 | 154.5056 | 115.3124 | 94.3415 | 65.18631 | 40.09224 | 32.68481 |
| 拟合斜率 | 1.940232195 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 斜率标准差 | 0.072160936 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**（2）阻尼挡位：4；K=1**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 振幅θ | 182 | 132 | 113 | 96 | 82 | 70 | 60 | 51 | 44 | 37 | 32 | 27 | 23 | 19 | 16 | 14 |
| 时间t | 7.66 | 15.32 | 22.98 | 30.64 | 38.3 | 45.96 | 53.62 | 61.28 | 68.94 | 76.6 | 84.26 | 91.92 | 99.58 | 107.24 | 114.9 | 229.8 |
| yj = ln θj | 5.204006687 | 4.882802 | 4.727388 | 4.564348 | 4.406719 | 4.248495 | 4.094345 | 3.931826 | 3.78419 | 3.610918 | 3.465736 | 3.295837 | 3.135494 | 2.944439 | 2.772589 | 2.639057 |
| xj | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

求得：

|  |  |
| --- | --- |
| 直线斜率b1 | -0.16421621 |
| 对数缩减Δ | 0.164216212 |
| 阻尼比ς | 0.0261269 |
| 不确定度UΔ | 0.000273724 |
| 不确定度Uς | 0.040813116 |
| 时间常数τ | 9.333706025 |
| 品质因素Q | 19.13736415 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 周期 | 1.425 | 1.441 | 1.466 | 1.486 | 1.497 | 1.513 | 1.52 | 1.526 | 1.531 | 1.537 | 1.541 | 1.552 | 1.555 | 1.571 | 1.58 | 1.595 | 1.611 | 1.647 |
| 频率 | 4.409252847 | 4.360295 | 4.285938 | 4.228254 | 4.197185 | 4.152799 | 4.133675 | 4.117422 | 4.103975 | 4.087954 | 4.077343 | 4.048444 | 4.040634 | 3.999481 | 3.9767 | 3.939301 | 3.900177 | 3.814927 |
| 振幅θ | 23 | 29 | 41 | 49 | 57 | 68 | 72 | 80 | 80 | 82 | 80 | 76 | 73 | 57 | 49 | 41 | 34 | 25 |
| 相位差 | 161 | 160 | 154 | 144 | 135 | 124 | 114 | 108 | 100 | 91 | 88 | 65 | 50 | 42 | 37 | 29 | 24 | 19 |
| 求得ω0（Hz） | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 | 4.088 |
| 相位差计算值(弧度制) | -0.33224844 | -0.38471 | -0.50465 | -0.65891 | -0.78094 | -1.02893 | -1.16869 | -1.30291 | -1.42261 | 1.570366 | 1.471217 | 1.214519 | 1.15121 | 0.873343 | 0.757858 | 0.614054 | 0.506893 | 0.361061 |
| 相位差计算值(角度制) | 160.9635665 | 157.9575 | 151.0859 | 142.247 | 135.2557 | 121.0464 | 113.0388 | 105.3486 | 98.49017 | 89.97533 | 84.2945 | 69.5868 | 65.95947 | 50.03886 | 43.42204 | 35.18269 | 29.04281 | 20.68727 |
| 相位差偏差 | 0.036433491 | 2.04247 | 2.914126 | 1.753036 | -0.25572 | 2.953616 | 0.961182 | 2.651389 | 1.509835 | 1.024673 | 3.705503 | -4.5868 | -15.9595 | -8.03886 | -6.42204 | -6.18269 | -5.04281 | -1.68727 |
| 振幅计算值 | 27.54918537 | 32.69078 | 45.37066 | 64.47503 | 83.1325 | 140.8299 | 200.2626 | 311.5069 | 574.6617 | 199983.6 | 864.2077 | 233.6624 | 195.32 | 105.0477 | 83.78171 | 63.0024 | 50.12312 | 34.84721 |
| 拟合斜率 | 257.0965113 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 斜率标准差 | 180.28365 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**（3）阻尼挡位：5；K=1,**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 振幅θ | 156 | 127 | 104 | 85 | 70 | 58 | 48 | 41 | 34 | 28 | 23 | 19 | 16 | 13 |
| 时间t | 7.66 | 15.32 | 22.98 | 30.64 | 38.3 | 45.96 | 53.62 | 61.28 | 68.94 | 76.6 | 84.26 | 91.92 | 99.58 | 107.24 |
| yj = ln θj | 5.049856007 | 4.844187 | 4.644391 | 4.442651 | 4.248495 | 4.060443 | 3.871201 | 3.713572 | 3.526361 | 3.332205 | 3.135494 | 2.944439 | 2.772589 | 2.564949 |
| xj | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |

求得：

|  |  |
| --- | --- |
| 直线斜率b1 | -0.18875245 |
| 对数缩减Δ | 0.188752451 |
| 阻尼比ς | 0.030027339 |
| 不确定度UΔ | 0.00013468 |
| 不确定度Uς | 0.026699883 |
| 时间常数τ | 8.121292419 |
| 品质因素Q | 16.65149191 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 周期 | 1.425 | 1.454 | 1.467 | 1.483 | 1.498 | 1.512 | 1.525 | 1.532 | 1.535 | 1.543 | 1.555 | 1.57 | 1.579 | 1.595 | 1.621 | 1.652 |
| 频率 | 4.409252847 | 4.32131 | 4.283017 | 4.236807 | 4.194383 | 4.155546 | 4.120122 | 4.101296 | 4.09328 | 4.072058 | 4.040634 | 4.002029 | 3.979218 | 3.939301 | 3.876117 | 3.803381 |
| 振幅θ | 23 | 32 | 38 | 45 | 53 | 60 | 64 | 65 | 65 | 62 | 58 | 50 | 44 | 39 | 31 | 25 |
| 相位差 | 155 | 148 | 145 | 138 | 128 | 115 | 100 | 90 | 87 | 78 | 64 | 50 | 44 | 35 | 29 | 23 |
| 求得ω0（Hz） | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 | 4.098 |
| 相位差计算值(弧度制) | -0.38893341 | -0.51478 | -0.59702 | -0.73351 | -0.91194 | -1.13602 | -1.39339 | -1.54403 | 1.532438 | 1.362374 | 1.131841 | 0.902629 | 0.795649 | 0.649915 | 0.494474 | 0.382308 |
| 相位差计算值(角度制) | 157.715757 | 150.5053 | 145.7934 | 137.973 | 127.7495 | 114.9109 | 100.1646 | 91.53366 | 87.80223 | 78.05827 | 64.84969 | 51.71686 | 45.58732 | 37.2374 | 28.33127 | 21.90463 |
| 相位差偏差 | -2.71575698 | -2.50527 | -0.79336 | 0.027032 | 0.250506 | 0.089068 | -0.16462 | -1.53366 | -0.80223 | -0.05827 | -0.84969 | -1.71686 | -1.58732 | -2.2374 | 0.668729 | 1.095365 |
| 振幅计算值 | 28.53998551 | 40.1949 | 48.73591 | 65.32033 | 94.55357 | 159.1116 | 415.6895 | 2796.449 | 1954.758 | 356.5544 | 161.863 | 97.21409 | 78.76698 | 59.24782 | 42.71195 | 32.46329 |
| 拟合斜率 | 10.35405481 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 斜率标准差 | 3.683217424 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

结论：此法求出的和方法一中求出的值接近，则在某些计算中可以使用方法一中的估测值。

拟合斜率和理论值存在较大偏差，初步分析则发现，主要的偏差是由相位差在90度附近的几个点导致的，而在这些点，振幅甚至超过180，而这是不允许的，因为此时能量会抵消耗散掉；其它原因可能是在阻尼运动时少考虑了某种阻力或测得的阻尼比较小。

1. **幅频、相频特性曲线**

**五、讨论：**

误差分析：（1）在实验的分析过程中，将阻尼系数视为一个常值，而当振动幅度较大，运动速度较快时，阻尼系数可能变化；

1. 在实验中，电机转速可能不稳定，扭摆可能存在偏心，使得测量时扭摆不稳定，带来误差；
2. 弹簧的弹力可能存在非线性效应；
3. 实验时若未等示数稳定再读数，则会导致误差；

探究性：（1）理论上，受迫振动共振点对应的频率应当小于，但是实验中出现了接近甚至大于的情况，这一方面是由实验的精度导致的，另一方面可能和电机的不稳定有关；

（2）发现很多时候共振点对应的相位差不是90度；

思考题：（1）可以通过判断观察振幅和频率是否都稳定受迫振动是否已处于稳定状态；

（2）结果接近；

（3）结果接近，令导数为零可得;

阻尼比较小时，则和余弦函数等于1的时候相当；

**原始数据**

**图片包含 文字

描述已自动生成图片包含 文字

描述已自动生成**