TMA 4115 Matematikk 3

Lecture 8 for MTFYMA

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In this lecture we discuss:

- More on the forced harmonic motion
- Solving inhomogeneous equations by "Variation of parameters"

A general solution to the inhomogeneous equation

$$y'' + p(t)y' + q(t)y = f(t) \tag{1}$$

is of the form

$$y(t) = y_p(t) + Ay_1(t) + By_2(t), A, B \in \mathbb{C}.$$

Here

1. y_1, y_2 are a fundamental system for the associated homogeneous system
2. y_p is a particular solution to the inhomogeneous system

If the forcing term $f(t)$ is "nice" we can use the *method of undetermined coefficients* to compute y_p in step 2.

Method of undetermined coefficients

Guideline for the method

If the form of the forcing term f replicates under differentiation, look for a solution with the same form (with a parameter).

Complex method for trigonometric terms

Solve

$$y'' + p(t)y' + q(t)y = f(t)$$

for forcing term $f(t) = A\cos(wt)$ or $f(t) = A\sin(wt)$ with $A \in \mathbb{R}$.

Idea: $A\cos(wt) = \mathrm{Re}(Ae^{wit})$ and $A\sin(wt) = \mathrm{Im}(Ae^{wit})$.

Strategy

- Find a particular solution z_p of $z'' + p(t)z' + q(t)z = Ae^{wit}$
- The real part of z_p solves the equation for $y'' + p(t)y' + q(t)y = Acos(t)$ (imaginary part yields solution for forcing term $A\sin(wt)$)

5.8 Example $y'' + 2y' - 3y = 5\sin(3t)$

Solving $z'' + 2z' - 4z = 5e^{3it}$ we get $y_p(t) = -\frac{2+i}{6}e^{3it}$.

$$\begin{aligned} -\frac{2+i}{6}e^{3it} &= \frac{1}{6}(-2\cos(3t) - i\cos(3t) - 2i\sin(3t) - i^2\sin(3t)) \\ &= -\frac{1}{3}\cos(3t) + \frac{1}{6}\sin(3t) - i(\frac{1}{6}\cos(3t) + \frac{1}{3}\sin(3t)) \end{aligned}$$

$y_p(t) = \mathrm{Im}(-\frac{2+i}{6}e^{3it}) = -\frac{1}{6}\cos(3t) - \frac{1}{3}\sin(3t))$
(same as in Example 5.3)

Forced harmonic motion: Undampened case

Consider a forced harmonic motion

$$y'' + 2cy' + \omega_0^2 y = A\cos(\omega t), \qquad A \neq 0 \tag{7}$$

with $c, \omega_0, \omega \in \mathbb{R}$ and

c, the dampening parameter

ω_0, the natural frequency

ω, the driving frequency

Assume that $c = 0$, i.e. no damping in the harmonic motion.

Fundamental set of solutions for (7) and $c = 0$ is

$$y_1(t) = \cos(\omega_0 t), \qquad y_2(t) = \sin(\omega_0 t)$$

Case 1: $\omega \neq \omega_0$

Use undetermined coefficients to solve (7) for $c = 0$.

Trial solution:

$y_p(t) = a\cos(\omega t) + b\sin(\omega t)$.

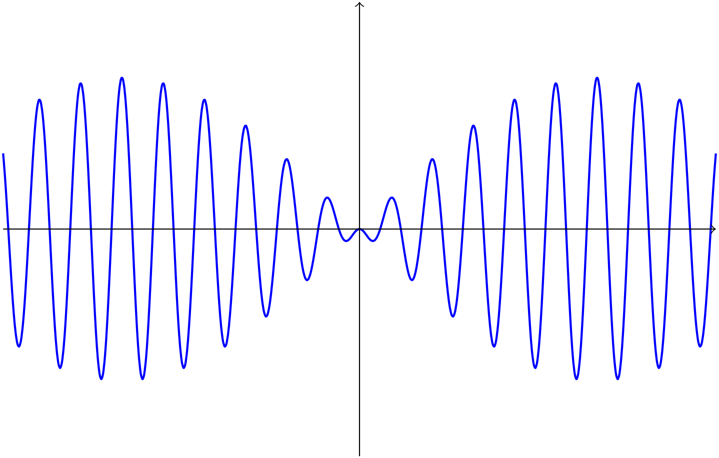
Insert in (7) and solve to find $a = \frac{A}{\omega^2 - \omega_0^2}$, $b = 0$ whence

$$y(t) = \frac{A}{\omega^2 - \omega_0^2}\cos(\omega t) + r\cos(\omega_0 t) + s\sin(\omega_0 t), \quad r, s \in \mathbb{R}$$

is the general solution to (7).
Solving the IVP (7), $y(0) = 0, y'(0) = 0$ yields

$$y(t) = \frac{A}{\omega^2 - \omega_0^2}(\cos(\omega t) - \cos(\omega_0 t))$$

Example plot: $A = 23, \omega = 12$ and $\omega_0 = 11$



Case $\omega_0 \neq \omega$: Fast oscillation with slowly varying amplitude

Case 2: $\omega = \omega_0$

For $\omega = \omega_0$ the trial solution solves the homogeneous equation.

Trial solution

$t(a\cos(\omega t) + b\sin(\omega t))$ (Multiply trial solution from Case 1 by t)

Solve to find

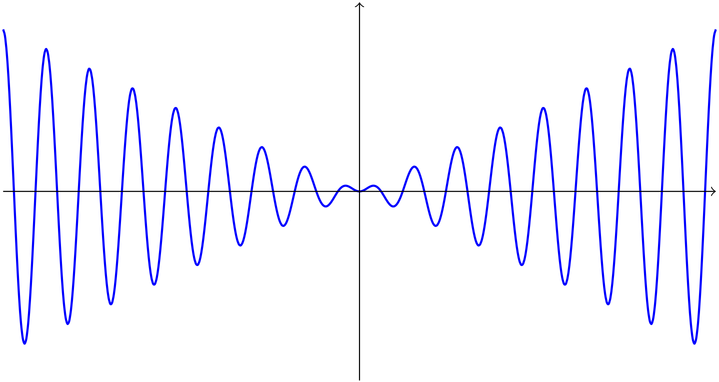
$$y(t) = \frac{A}{2\omega_0} t\sin(\omega_0 t) + r\cos(\omega_0 t) + s\sin(\omega_0 t), \;\; r, s \in \mathbb{R}$$

the general solution to (7). With initial conditions $y(0) = 0, y'(0) = 0$ this reduces to

$$y(t) = \frac{A}{2\omega_0} t\sin(\omega_0 t)$$

Example plot: $A = 7, \omega = \omega_0 = 11$

The solution $y(t) = \frac{7t}{22}\sin(11t)$



Case $\omega_0 = \omega$: The amplitude grows linearly with time

6. Inhomogeneous equations: Variation of parameters

Method of undertermined coefficients works only for “nice” forcing terms.

Goal now, construct solutions for arbitrary f and

$$y'' + p(t)y' + q(t)y = f(t) \tag{1}$$

Idea: To find a particular solution set

$$y_p(t) = v(t)y_h(t)$$

where y_h solves the homogeneous equation,
v is an unknown function.
Insert into equation to find v!

6.2 Summary of the method

- We need a fundamental set y_1, y_2 of solutions to $y'' + p(t)y' + q(t)y = 0$.
- Define $y_p(t) = v_1(t)y_1(t) + v_2(t)y_2(t)$ with unknown functions v_1, v_2
- Solve

$$v_1(t) = \int \frac{-y_2(t)f(t)}{y_1(t)y_2'(t) - y_1'(t)y_2(t)}dt$$
$$v_2(t) = \int \frac{y_1(t)f(t)}{y_1(t)y_2'(t) - y_1'(t)y_2(t)}dt$$

to obtain y_p.

Alternatively, if you can't remember the formula: Derive it as explained in the lecture **6.1**.