MEC4047F - Mechanical Vibrations

University of Cape Town:
Department of Mechanical Engineering

Project 2

Overview

A local business owns a multi-storey building and needs to transport goods to the upper levels for storage. Transporting the goods by hand is not possible due to the total volume and item mass that needs to be stored. The business owner wants to make a temporary lifting apparatus from items they already own, to keep costs down. You have been asked to evaluate their proposed design as a favour.

The plan is to build a pulley system in the stairwell of the building using old steel automobile wheels as the pulleys and an old climbing rope. One of the wheels will have a crank arm attached to it which will be manually cranked to lift the payload. The crank pulley and two additional pulleys will be mounted in the roof space of the building. The crank pulley is mounted to brickwork and the other two pulleys are mounted to a ceiling joist (wooden beam) that is supported by brickwork 1 m apart. A fourth pulley is mounted to a moving load-spreader which ensures the payload platform remains level. The rope will be attached to the load-spreader and will run through the pulleys as shown in Figure 1. The pulleys are positioned such that the rope runs either horizontally or vertically between each pulley.

The lifting platform will be free-hanging at the delivery level and goods will be offloaded at three storage levels, each 4 m above the previous level.

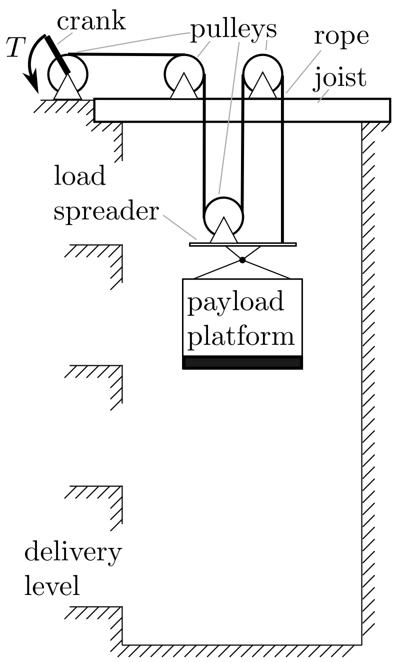

Figure 1: Make-shift lifting system

Core skills

In completing this project you will demonstrate that you are able to:

- Develop a mathematical model of a complex dynamic system by making appropriate engineering assumptions and simplifications and applying dynamics and vibration theory.
- Implement the mathematical model in Python.
- Use SciPy functions to determine the vibration characteristics of the system.
- Use the vibration characteristics of the system to make determinations about the system based on specified requirements.

Motivation

The project is used to ensure graduates leaving the undergraduate programmes offered by the department have demonstrated ECSA graduate attribute (GA) 2 at a level appropriate for a graduate engineer.

ECSA graduate attribute 2:
Application of scientific and engineering knowledge

The graduate attribute requires that you:
Apply knowledge of mathematics, natural sciences, engineering fundamentals and an engineering speciality to solve complex engineering problems.

The level descriptor for the GA is:
Knowledge of mathematics, natural sciences and engineering sciences is characterized by:

- A systematic, theory-based understanding of the natural sciences applicable to the discipline;
- Conceptually-based mathematics, numerical analysis, statistics and formal aspects of computer and information science to support analysis and modelling applicable to the discipline;
- A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline; and
- Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.

Where and how is this learning objective assessed?

This outcome is assessed in part one of this project.

What constitutes satisfactory performance?

A student must propose a multi-degree-of-freedom vibration model that is suitable for the analysis laid out in this project. The vectorised equations of motion representing the model must have been correctly derived. Engineering choices and simplifications related to choices of DOFs and developing the EOMs must be justified with appropriate calculations and logical reasoning. This is assessed in Part 1 of the project, for which a sub-minimum of 80% is required to satisfy the GA.

What strategy is to be followed should this learning objective not be satisfactorily attained?

Students who do not meet the GA after the initial assessment will be invited to resubmit part 1 of the project. This re-submission will be reassessed. If the GA is still not met, one of the sub-minimums for the course will not have been met and the course must be repeated in the subsequent year.

Component Details

You will be provided with individualised properties for certain items to be used in the lifting system. These items will be the wheels to be repurposed as pulleys, the rope to be used, the mass of the unladen lifting platform, and the mass of the payload.

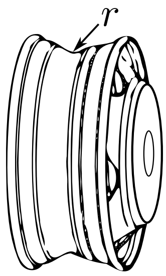

Figure 2: Diagram of wheel indicating radius provided

The pulleys will be made from repurposed automotive wheels that do not have tyres attached to them. The wheels are attached to hubs that run on bearings mounted on fixed axles. Each hub-bearing-axle assembly has a total mass of 25 kg of which the moving components have a mass-moment of inertia of $0.1\,\mathrm{kg\,m^2}$.

The joist is made of sawn South African Pine which is 50 mm wide and 152 mm high. The effective elastic modulus of SA Pine is 10 GPa. You do not need to assess the joist for mechanical strength.

The rope is a dynamic climbing rope which has a given mass and elastic modulus per metre. The maximum safe load for the rope is 20 kN.

The crank arm is constructed of a 800 mm length of 40 mm square steel tubing with a wall thickness of 3 mm which is welded to one of the wheels/pulleys. The crank handle is made of a 400 mm length of 20 mm diameter solid steel bar. The crank handle radius is 600 mm.

Project requirements

Part 1

1. Simplify the system into a multi-degree-of-freedom vibration model. You should include a sufficient number of degrees of freedom to appropriately answer the questions below.

2. Justify your choice of degrees of freedom with appropriate calculations and/or logical reasoning. If you choose to neglect the independent motion of a body with a given mass, you must explain why.

3. Find the symbolic linearised equations of motion for your model in matrix-vector form.

4. How do the mode shapes and modal frequencies of both fully-laden and unladen systems change for each level the platform is used? You should use Eigen solver functions in NumPy or SciPy rather than solving these by hand.

Note that the development of the EOMs may be via momentum or energy methods (Newtonian or Lagrangian approach). You must properly document either process, making use of Free Body Diagrams to justify force balances and/or clear illustration of deforming or moving elements, as appropriate. Incorrect diagrams and equations which are inconsistent with diagrams will be heavily penalised. Final EOMs which don't make physical sense without suitable explanation will be heavily penalised.

Part 2

1. Develop a numerical approximation for the displacement-time response of a multi-DOF system, where the mass, stiffness and damping matrices are known inputs. You may use SciPy or NumPy solvers, or develop your own Python implementation of the central difference method. Whichever case, you must verify that your numerical approximation is accurate for a two DOF system with a time-varying force input and document the verification process.

2. Using your numerical approach, investigate how the torque on the crank pulley varies over time if the payload you have been allocated is dropped onto the lifting platform from a height of 200mm, assuming the crank stays stationary. How is this affected by the building level at which loading occurs?

3. Are there any scenarios you think an engineer might wish to model dynamically for which the model you propose is not suitable?

4. Alternate ropes are available with higher tensile stiffness. For the most relevant configuration, discuss the relative merits and downsides of a stiffer rope, assuming the rope mass is not affected.

5. If they were strong enough, how would using bicycle wheels instead of car wheels affect how you might model the system?

Mark Breakdown

The table shows an approximate allocation of marks for each part of the submission.

	Item Description	Weight
Part 1	Choice of DoFs with reasoning and supporting calculations	15%
	Development of system model and Derivation of EoMs	35%
	Discussion of mode shapes and frequencies	10%
Part 2	Verification of numerical approx. for 2 DoF	8%
	Dropped payload investigation	17%
	Discussion of model variants	10%
	Report & Presentation	5%

Submission requirements

The project is due at 11:00 on Monday 13 May 2024. You are only required to submit a digital submission.

You should submit a single Python file named with your student number (*e.g.* `ABCDEF001.py`) and a *brief* report written in Word or LaTeX and saved in PDF format.

The report must include a plagiarism declaration and an appropriate reference list.

Late submissions will be penalised 10% for each day or part thereof after the due date and time up to a maximum of 3 days after which your project will be marked for the GA alone, but you will not be awarded any marks.