Université d'Ottawa
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Faculty of Engineering

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FIRST NAME: ______________________________

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STUDENT #: ______________________________

MCG 2101

Introduction to Design of Mechanical Systems

Final exam — Time: 3 hours
April 14th, 2025 — José Morán, Ph.D., Assistant Professor

CLOSED BOOK. NO NOTES, BOOKS OR ALPHANUMERICAL CALCULATORS PERMITTED. NO PHONES / SMARTWATCHES / DEVICES ON YOU, AT ALL. INSTRUMENTS FOR HAND DRAFTING ALLOWED.

This questionnaire **must be identified and returned** with all pages in.

If you do not understand a question, make a reasonable assumption and proceed. At the end of the exam, when the time is up:

- Stop working and return your questionnaire.
- Stay silent.
- Do not speak and do not move until all copies are picked up, and the proctor or professor authorises you to leave.

The exam is worth 40% of your final mark for the course.

The exam features 2 sections (Sections A and B) worth 25 and 15 marks each for a total of 40 marks.

Section A features 3 design problems. Answer each question from Section A on the exam booklet.

Section B features 15 questions worth 1 mark each, which are all mandatory. Answer All questions of Section B directly on the exam booklet and add justification for all your answers. Answers without justifications will not be considered valid.

Section A: Design problems (25/40)
! ANSWER ON THE EXAM BOOKLET !
! MAKE SURE TO IDENTIFY IT !

[10/40] Problem 1: Propose a combination of mechanisms

An Ontario family has been running a local cookie manufacture company for 10 years. So far, they have made cookies based on manual methods to produce the dough and to cut-out the desired circular shapes of cookies as can be seen in **Figure 1**.

Figure 1: Old manual method for dough cut-out to produce cookies.

However, recently the company signed a big agreement with a delivery company in Quebec to produce cookies at a significantly higher rate which requires automation of the production line. The company is interested in replacing the classic manual cut-out process (**Figure 1**) by a new automatic mechanical system as shown in **Figure 2**. Here, we can see how the dough will be produced automatically and transported in a conveyor belt at constant speed. As can be seen in **Figure 2**, the company has available a set of 4 metallic cutout molds (referred with labels A, B, C and D in **Figure 2**). As can be seen in this figure, the movement of cutouts molds A and C (in red) as well as B and D (in green) needs to be synchronized to minimize the waste of cookie dough during cut-out. Furthermore, the company has available an electric motor that must be used as a constant rotational speed input motion.

The company has also the following restrictions and criteria to consider for your design:

- Input motion (electric motor) is a constant speed, continuous rotation;
- The electric motor shaft features a keyway on its end;
- The output motion of cutouts A and C as well as B and D are synchronized;

- The cutting molds must come back up after conducting the cut-out to allow the cookie dough to move on the conveyor belt and thus keep the production line working continuously;
- Of course, we must not ruin the shape of the cookies during the cut-out process;
- The company wants to minimize the waste of dough during the cut-out process;
- The number of components must be minimized. An economic and compact design is needed.

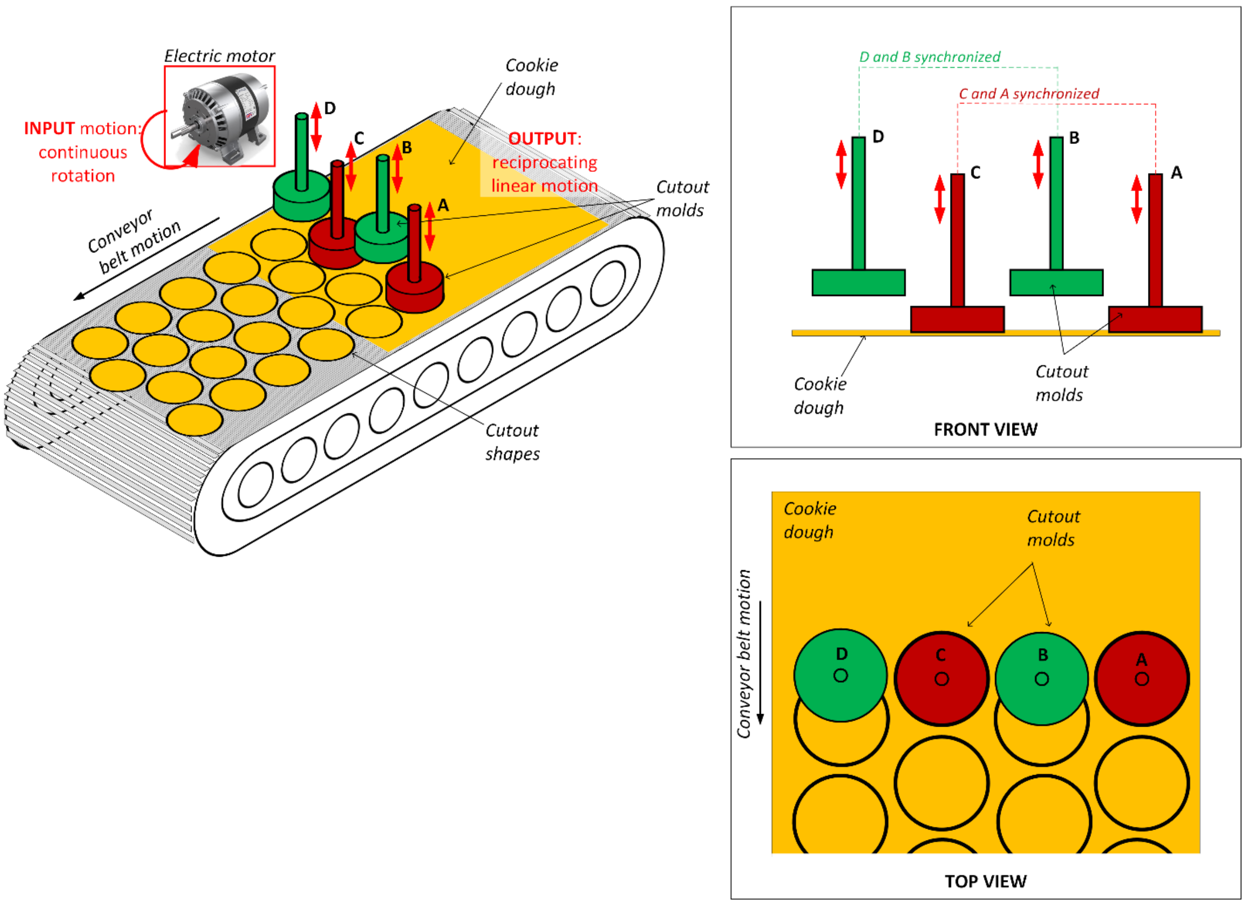


Figure 2: New automatic method for dough cutting to produce cookies.

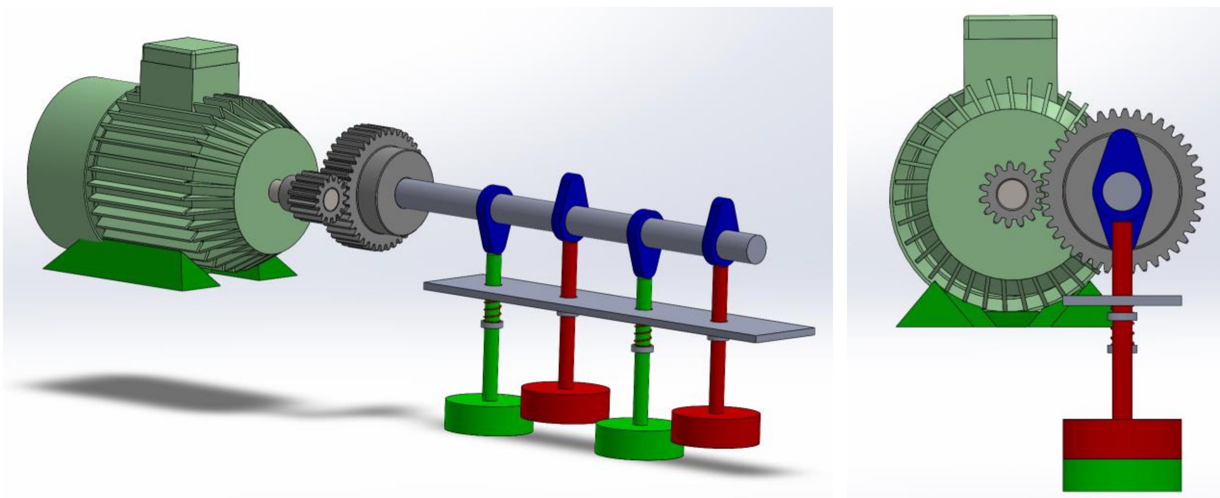
Propose a mechanism or a combination of mechanisms to conduct the dough cut-out process in this continuous production line using the 4 cutout molds and the electric motor available.

a) **[5 marks]** You are expected to **propose a concept** (a complete solution) to convert the input rotational motion into the output synchronized reciprocating linear motion needed here in this cut-out process. You must incorporate a simplified drawing (not necessarily a technical draft) to support your answer.

b) **[5 marks]** Write down a detailed **justification for each mechanism added to your design**. Mention other alternatives to each selected mechanism and explain why the chosen one are more appropriate for this particular problem.

Answer to problem 1 (page 1/2):

[5 points] There are different types of solution that could be considered for this problem. The problem consists in converting a continuous rotary motion into an alternating linear motion. The two mechanisms we have studied for this purpose are: cam-follower and slider-crank. The slider-crank system is less suitable in this case, as the cutout molds are rigid and don't allow for crank rotation rotation associated with this mechanism. Other types of mechanism that are less obvious for this problem, and which also enable us to convert rotary motion into reciprocating linear motion, are the Scotch-yoke, the rotary-to-linear system, or the quick-return mechanism. One of the simplest solutions, which minimizes the quantity of mechanical components, is shown in the image below. The key elements are described as follows:

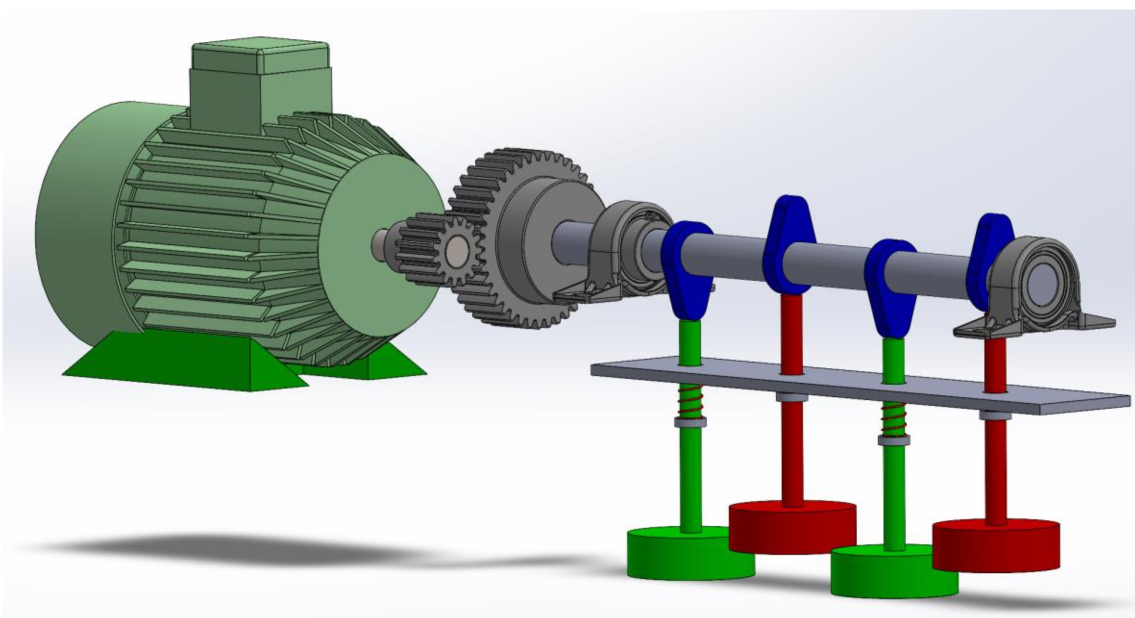


Note: If you proposed another mechanical system that works properly (e.g. with linear cams or other types of mechanism), you'll get proportional points according to: design that works properly, economical design, minimum quantity of components.

1. **[1 point] A speed reducer:** Electric motors normally run too fast to be directly connected to the main drive shaft (e.g. with couplings), so at least one speed reduction stage is required. At least we should think and consider adapting the speed of rotation from the electric motor (well justified hypotheses were also considered). In this case, we've opted for two spur gears, as they minimize the number of components, are economic and provide a compact design, which are important considerations when compared with the choices such as belts and chains. As the motor output shaft already contains a keyway, the pinion mounting is normally straightforward. Alternatives such as belt or chain systems are also considered possible answers but are less suited to this problem.
2. **[1 point] Camshaft:** This type of shaft allows the transfer of rotational motion from the gear to 4 radial cams as shown in the image above. It is important to consider the cams connected to the cutout molds A and C as well as B and D exactly aligned to have a synchronized operation as needed here. However, we have to consider an angular shift of exactly 180*

between the two pairs of synchronized cams in order to achieve the alternating motion required here.

3. **[1 point] Cam-follower system:** The design of each cam-follower system should always keep the follower in contact with the cam. We could simply consider the extreme side of the mold bar as a flat-faced in-line follower or add a specific follower such as roller to reduce wearing. Cam geometry must be calculated to have the correct timing to cut the dough at the precise moments to minimize dough wastage and avoid damaging the cut cookie shape. The radial difference between the cam's max and min points must be greater than the thickness of the dough to be cut to avoid damaging the dough itself.
4. **[1 point] Spring:** We also added a spring for each cam-follower system used here with the aim of keeping the cam always in contact with the follower but also to avoid damaging the cookie dough (a restriction mentioned by the customer). We have provided a simplified solution for mounting springs with a horizontal wall with holes to allow mold movement. The springs are installed in a compression configuration to force the molds to rise each time the cut is finished and keep the follower in contact with the cam. Additional mechanisms (e.g., bushing) could be added to reduce wear between the mold bar and this wall.
5. **[0.5 points] Bearings:** We cannot install a shaft without mentioning how it will be mounted, allowing it to rotate. As shown in the image below, our choice of bearings is simply ball bearings to support the radial loads associated with the gears and cams-follower interaction. We have assumed a horizontal surface available for mounting the bearings with pillow block mechanisms.
6. **[0.5 point] Other mechanisms:** Additional points are given to students specifying the mechanisms used to mount components on the camshaft (mounting gears, bearings and cams). Cams are not necessarily mounted on the shaft but can be machined during the manufacture of the drive shaft.



[5/40] Problem 2: Cam design

In the context of a mechanical design project, you and your work team need to design a cam-follower mechanism. For this end, you have decided to use the mathematical method. Derive equations to describe segments of a displacement diagram of a radial cam that rises with a sinusoidal equation ($y(\theta) = A\sin[B\theta + C] + D$ where θ is the cam angle. A, B, C, and D are constants to be found) of motion from a dwell to another dwell such that the total lift is 2L and the total cam angle is 2β.

a) **[2 mark]** Could the segments describing the motion of the cam be different straight-lines instead of the sinusoidal profile selected? Justify your answer.

Answer: No! linear profiles produce mathematically indefinite slopes at the points of intersection of the linear segments. This completely disrupts the operation of the cam-follower system and makes it impossible to keep the follower in contact with the cam.

b) **[3 marks]** Find equations of motion describing the first-, second-, and third-order kinematic coefficients.

[1 point] We may simply express the following 4 conditions to search for 4 unknown constants (A,B,C, and D), without need to divide the problem into a piecewise function:

$$y(0) = 0; \left.\frac{\partial y}{\partial \theta}\right|_{\theta=0} = 0;\ y(2\beta) = 2L; \text{et } \left.\frac{\partial y}{\partial \theta}\right|_{\theta=2\beta} = 0,$$

[1.5 point] Obtain the constants A, B, C, et D,

$$\left.\frac{\partial y}{\partial \theta}\right|_{\theta=0} = A\cos[C]B = 0 \rightarrow \boldsymbol{C = \frac{\pi}{2}}$$

Note: Other values for C could have been chosen too: $-\frac{3\pi}{2}, -\frac{\pi}{2}, \frac{\pi}{2}, \frac{3\pi}{2}, \ldots.$

$$\left.\frac{\partial y}{\partial \theta}\right|_{\theta=2\beta} = A\cos\left[B2\beta + \frac{\pi}{2}\right]B = 0 \rightarrow\ B2\beta + \frac{\pi}{2} = -\frac{\pi}{2} \rightarrow \boldsymbol{B = -\frac{\pi}{2\beta}}$$

$$y(\theta = 0) = A\sin\left[\frac{\pi}{2}\right] + D = 0 \rightarrow A = -D$$

$$y(\theta = 2\beta) = A\sin\left[-\left(\frac{\pi}{2\beta}\right)2\beta + \frac{\pi}{2}\right] + D = 2L \rightarrow -A + D = 2L \rightarrow \boldsymbol{A = L}$$

[0.5 points] Kinematic coefficients are:

$$\boldsymbol{y(\theta) = L\left(1 - \sin\left[-\frac{\pi\theta}{2\beta} + \frac{\pi}{2}\right]\right)}$$

$$\boldsymbol{y'(\theta) = -L\frac{\pi}{2\beta}\cos\left[-\frac{\pi}{2\beta}\theta + \frac{\pi}{2}\right]}$$

$$\boldsymbol{y''(\theta) = -L\left(\frac{\pi}{2\beta}\right)^2 \sin\left[-\frac{\pi}{2\beta}\theta + \frac{\pi}{2}\right]}$$

$$\boldsymbol{y'''(\theta) = L\left(\frac{\pi}{2\beta}\right)^3 \cos\left[-\frac{\pi}{2\beta}\theta + \frac{\pi}{2}\right]}$$

[10/40] Problem 3: Gear train design

Propose a functional design of a constant, single ratio gear speed reducer where the axes of the input and output shafts are perpendicular.

- Speed ratio is 25;
- Power is supplied by an electric motor of 27.96 kW. This rotating motion has to be transferred to the input shaft of your gear train;
- The input angular speed is 1750 rpm.
- We want to keep the design as economic and as compact as possible.
- High efficiency (>95%) is required for this gear train.

Number of Pinion Teeth, N_P	Number of Gear Teeth, N_G — Helix angle, ψ, deg: 0	5	10	15	20	25	30	35
8								12
9							12	34
10						12	26	∞
11					13	23	93	
12			12	16	24	57	∞	
13	16	17	20	27	50	1385		
14	26	27	34	53	207			
15	45	49	69	181	∞			
16	101	121	287	∞				
17	1309	∞	∞					

Max # gear of teeth

Min # of gear teeth

gear is N_P.

Note: make any engineering assumption that you deem necessary regarding loads, operating conditions and any other aspect of the reducer, and state these assumptions clearly in the booklet. Your assumptions, if any, cannot contradict the information provided above. A table of minimum and maximum teeth numbers for pinions and gears is provided above.

a) **[5 marks]** What is your choice for gear configuration and type(s)? Justify this by discussing their advantages. Specify the rotation speed and number of teeth of each gear selected.

Answer:

[3 points] The gear ratio is normally too high for a single-stage gear system, unless a worm gear is used, which would seem to be a good solution for shafts in perpendicular configuration. However, the high energy efficiency (>95%) requirement prevents us from choosing this gear. So, starting from the need for an economical and compact configuration, we can choose bevel gears for the first stage to enable a 90-degree configuration. A gear ratio of 5 can be chosen for the first stage. For the second stage, we can also choose a gear ratio of 5 with spur gears. So, the total reduction is 5*5=25. Of course, we could add more stages, but we need a compact design, so we keep the number of stages at minimum. As there are no noise-related criteria for the mechanical system, and to have an economical design, we're going to choose gears with straight teeth. Justifications of the gear type based on speed and torque are considered. Below we specify the gear properties of the speed reducer:

[1 point] Stage 1:

$$w_{p,1} = 1750 \text{ rpm}$$

$$n_1 = 5 = \frac{w_{p,1}}{w_{g,1}} = \frac{N_2}{N_1}$$

$$w_{e,1} = 350 \text{ rpm}$$

We could select $N_1 = 17$ for the first pinion which allows possible values of N_2 below 100 teeth, thus,

$$N_2 = 17 * 5 = 85$$

We verify that no common factors exist between N_1 and N_2.

[1 point] Stage 2:

In the same shaft of the gear of stage 1 we will connect the gear of stage 2 (thus $w_{g,1} = w_{p,2}$),

$$w_{p,2} = 350 \text{ rpm}$$

$$n_1 = 5 = \frac{w_{p,1}}{w_{g,1}} = \frac{N_2}{N_1}$$

$$w_{g,1} = 70 \text{ rpm}$$

We could select $N_1 = 16$ for the pinion which allows possible values of N_2 below 100 teeth, thus,

$$N_2 = 16 * 5 = 80$$

Here we verify the existence of common factors between N_1 and N_2. Therefore, we can select $N_2 = 81$. This will slightly increase the speed ratio and $w_{g,1}$ should be recalculated to obtain its exact value.

b) **[5 marks]** How do you attach the gears to the shafts? Identify the methods clearly for each gear and justify your selection.

Answer:

[5 points] The power and speeds of the problem give us the freedom to choose the type of method for attaching gears to shafts designed for medium and high torques. So, different types of keys (parallel, Woodruff), pins or engagement splines are options to consider. In this case, the most economical option will be the parallel key, as many gears are designed with this type of mounting solution and will therefore be more economical to implement. Considerations of different attachment according to induvial gears based on torque and speed are taken into account.

Section B (15/40)

! ANSWER EACH QUESTION HERE BELOW AND JUSTIFY ALL YOUR ANSWERS (NON-JUSTIFIED ANSWERS WILL BE PENALIZED WITH 50%)

! ANSWER ON THE EXAM BOOKLET, MAKE SURE TO IDENTIFY IT !

Note: Partial points are given for each question according to this formula:

$$\text{Grade} = \frac{(\#\ \text{Correct answers})}{(\#\ \text{Selected}\ + \#\ \text{Correct non selected})}$$

[15/40] Multiple choice questions (total = 15)

Theare are a total of 15 questions. Each of them is worth 1 mark. Read carefully, mark clearly your answer, and **justify all responses**. Non-justified answers will not be considered.

1. The following are important considerations when deciding to incorporate power screws into a design (Select all that apply):
   a) High loads can be handled
      [v] Justification: Power transmission screws are designed to withstand high loads, depending on the material, screw pitch and type of nut used. They are often used to lift heavy loads such as the jack screw mechanism or various tools such as those for cutting metal tubes/hoses or compressing springs.
   b) Accurate linear motion is needed
      [v] Justification: Drive screws, particularly ball screws, are used where precision linear motion is essential, such as in machine tools, industrial automation and robotics. They offer low backlash and smooth motion thanks to reduced friction.
   c) The need of drilling
      [x] Justification: Drilling is not a criterion directly related to the design or use of power transmission screws. However, it can be an important criterion when selecting screws for assemblies of different mechanical components (fasteners).
   d) High axial and radial forces exist
      [x] Justification: Power screws are primarily designed to support axial forces (in the axis of the screw). Radial loads are to be avoided altogether, collinear axial loads are acceptable, and eccentric axial loads are to be avoided.
   e) High speeds are involved
      [x] Justification: These mechanisms are not designed for high-speed applications, as high friction is associated with high energy losses.
2. In stage 3 of the DFMA (design for manufacturing and assembly), the Handling Analysis considers the following sub-analyses (Select all that apply):
   a) Size and weight
      [v] Justification: This is an analysis that seeks to minimize or avoid components that are too small or too heavy, and therefore difficult to handle.
   b) Handling difficulties

[v] Justification: This is an analysis that seeks to minimize or avoid components with different types of handling difficulties such as: fragile, flexible, sticky, abrasive, etc.

c) End-to-end orientation

[v] Justification: Seeks to favor components with symmetrical assembly or that are easy to see and therefore to handle.

d) Linear displacement

[x] Justification: Linear displacement is not one of the analyses to be carried out in connection with the handling of components.

e) Rotational orientation

[v] Justification: Prefer components with symmetrical assembly or that are easy to see and handle.

3. Converting <u>continuous rotation</u> into <u>intermittent rotation</u> is not simple. In this course we have studied only a few mechanisms able to do this task. They are (Select all that apply):

a) Scotch yoke

[x] Justification: This mechanism converts rotary motion into linear motion and vice versa.

b) Geneva wheel

[v] Justification: This mechanism converts a continuous rotation in one direction into an intermittent rotation in the opposite direction.

c) Ratchet

[x] Justification: This mechanism has 2 co-linear rotating parts, where one will drive the other by turning in one direction, but will turn freely in the other direction.

d) Sector gear

[v] Justification: This type of mechanism has one gear that rotates continuously and another that rotates intermittently.

e) Flange bushing

[x] Justification: Totally unrelated. Not even necessary to justify.

4. Power could, in principle, be transferred between two <u>parallel shafts</u> separated by some significant distance using the following mechanisms (Select all that apply):

a) Linkages

[x] Justification: Not directly. Linkages are not designed to transfer energy between parallel shafts.

b) Idle gears

[v] Justification: One of the applications of idle gears, i.e. "intermediate" gears, is precisely the transfer of torque between distant shafts.

c) Belts

[v] Justification: With the help of pulleys, belts are a suitable mechanism for this purpose.

d) Chains

[v] Justification: With the help of sprockets or sprocket wheels, chains are an ideal mechanism for this purpose.

   e) Clutches
      [x] Justification: They are not mechanisms designed to deal with distant shafts.

5. The single most critical aspect for the design of breaks and clutches that may lead to failure is (Select only one):
   a) The size of the discs
      [x]
   b) Managing temperature
      [v] Justification: Heat transfer, and in particular temperature rise, is a critical aspect of brake and clutch design, since in both cases surfaces are in friction either to reduce speed (brake) or to turn at the same speed (clutch).
   c) Resist wear
      [x]
   d) Quick response
      [x]
   e) Fits and tolerances
      [x]

6. The selection of shaft couplings is essentially based on (Select all that apply):
   a) Temperature, pressure, and relative humidity
   b) Shafts alignment
      [v] Justification: Depending on the shaft alignment requirement, there are various coupling system solutions, such as rigid or flexible couplings.
   c) Torques
      [v] Justification: Different types of couplings are designed to resist different levels of torque which allows optimizing costs.
   d) Rotation speed
      [v] Justification: Different types of coupling are suitable for different speeds which is directly a function of their design. For example, chain couplings are not suitable for higher speeds.
   e) The friction coefficient of the friction surface

7. Essential considerations for the design of bearings are (Select all that apply):
   a) Bearings must roll, and not slip in their casings /on their shafts
      [v] Justification: Slippage can lead to rapid wear and bearing failure.
   b) Both inner and outer rings must be simultaneously pre-loaded
      [x] Justification: No, just one of two rings must be preloaded for a bearing to work properly.
   c) Bearings can only be connected at the end of shafts
      [x] Justification: No, bearings can normally be mounted in all shaft positions, not just at the end.
   d) Higher loads can be handled by increasing the number of balls or increasing the contact area between rolling elements and the rings

[v] **Justification:** Exactly! It's one of the most fundamental principles of bearing design.

e) An economic option for mounting bearings on a wall or casings is welding

[x] **Justification:** No, welding bearings is a big mistake that must be avoided. There are specific mechanical components designed for mounting bearings to a wall, housing or casing.

8. The following aspects are essential to a design including spring mechanisms (Select all that apply):

a) Stiffness of the spring

[v] **Justification:** This determines the spring's spring constant k, a variable which has a direct impact on the spring's performance, since deformations and forces are directly related to this constant (Hooke's law).

b) Maximum compression and expansion of the spring

[v] **Justification:** Care must be taken to ensure that the spring is used within these operating limits, and for example to avoid approaching their elastic deformation limit.

c) The tolerances and fits

[v] **Justification:** Will have an impact on spring selection, installation and sizing.

d) The type and direction of loads

[v] **Justification:** Of course, the type and direction of loads will directly determine the choice of spring to be used. They will also determine whether a compression or tension spring is required.

e) Normally compressed or normally stretched mounting

[v] **Justification:** Determine the need for a compression or tension spring.

9. Select only the options that are **TRUE** regarding the design of mechanical systems (Select all that apply):

a) Additional restrictions could be added to the definition of the mandate even if the client did not mention them

[x] **Justification:** False, we should never add restrictions that are not specified by the client.

b) While criteria must imperatively be respected, restrictions should be optimized

[x] **Justification:** False, it's the opposite of what you'd normally do. The criteria are optimized, and the restrictions are strictly respected.

c) The purpose of the functional analysis is to decompose a complex problem into smaller and easier to solve problems associated to functions of the product

[v] **Justification:** Exactly, that's the reason for the name of the method.

d) Decisional analysis is, essentially, used to discard unfeasible solutions

[x] **Justification:** False, it is essentially used to select a solution from several possible solutions. Eliminating solutions that don't respect the restrictions is part of the decision analysis, but not the main or essential goal.

e) During decisional analysis, only restrictions are considered

[x] **Justification:** False, criteria are an essential part of decision analysis.

10. Select only the options that are **TRUE** regarding linkages (Select all that apply):
    a) Linkages can only be used to convert linear motion into rotating motion
    [x] Justification: No, linkages are not limited to converting linear motion into rotary motion. They can be used to convert continuous rotary motion into continuous rotary motion (e.g., drag-link mechanism), rotary motion into intermittent rotary motion (e.g., slider-crank), linear motion into linear motion (e.g., Scott Russel), etc.
    b) Linkages are assemblies of levers
    [v] Justification: Precisely, this is the definition of a linkage, which explains how it works and the need for pivots to assemble them.
    c) Bell-crank linkage mechanism can be used to change the direction of forces into 90 degrees
    [v] Justification: Makes objects or forces move in directions perpendicular to one another.
    d) In a 4-bar, 4-pivot linkage, the foundational link is still counted as such even though it is not necessarily a lever
    [v] Justification: Precisely, because the base segment must normally be a solid structure to connect the other linkage levers.
    e) Self-locking linkages are examples of 3 links, 3 pivots configurations
    [v] Justification: Precisely, we've even mentioned examples of "flip-flop" caps for bottles/jars that correspond to this type of linkage.
11. Select only the options that are **TRUE** regarding belts and chain (Select all that apply):
    a) Belts can be used in speed reducers systems but only at low speed ratios
    [v] Justification: Precisely, they are only used for speed ratios of less than 10 (roughly speaking) and low speeds of the order of 5 to 33 m/s.
    b) Belts require a precise alignment between pulleys
    [x] Justification: No, it's just that belts have more freedom of installation in this respect, as they don't need this precise alignment, and the belt can even be twisted using tensioners.
    c) Flat belts require a significant tension to avoid slippage
    [v] Justification: Precisely because of the geometry and the smooth surface of the pulleys which they are normally connected to, we need to ensure that they are maintained at a high level of tension. We've discussed different types of tensioners that enable us to keep the pulleys well connected.
    d) Cogged belts need the least tension of all belts and are among the most efficient
    [v] Justification: Specifically, their tension is generally lower than that of other belt types due to their notched geometry. Their mechanical efficiency can be > 98%.
    e) Continuously variable transmission (CVT) only allows a discrete number of speed ratios between two continuously rotating shafts
    [x] Justification: No, in fact, as indicated by its name: "continuously variable", this is a mechanism that allows us to have an infinite number of gear ratios.

12. What is the best solution for <u>connecting components to shafts</u>, such as gears, for high torque and high speed applications? (Select only one)
    a) Using keyways
    b) Retaining rings
    c) Using splines
    [v] Justification: Splines are used to engage shaft components such as gears or axial clutches. Splines suitable for high/very high torques and speeds - and all other situations. But more expensive than other solutions.
    d) Press fit connection
    e) Thermal expansion connection
13. Select only the options that are **TRUE** regarding <u>bearings</u> (Select all that apply):
    a) Ball bearings are commonly used for high load applications
    [x] Justification: False. This type of bearing is designed for low loads. Its design can be modified to increase its load capacity, by increasing the number of balls, which gives greater freedom for higher loads.
    b) Cylindrical roller bearings are not designed to support axial loads
    [v] Justification: This type of bearing is mainly designed to support heavy loads in the axial direction.
    c) Conical roller bearings are not designed to support axial loads
    [x] Justification: False. This type of bearing is designed to support both axial and radial loads (hence the idea of using a tapered geometry for the rolling element design).
    d) Lubrication of bearings is not critical because they are designed with materials minimizing friction
    [x] Justification: No! Bearing lubrication is critical, even if they are designed with materials or machinery processes that minimize friction.
    e) Alignment of inner and outer ring rotation axes is essential for the performance of bearings
    [v] Justification: If they're not properly aligned, there's a risk of unnecessary axial forces on the balls, or even interference.
14. Select only the options that are **TRUE** regarding <u>hydraulic and pneumatic systems</u> (Select all that apply):
    a) Pneumatic cylinders should not be loaded in bending
    [v] Justification: They are designed to support loads in the axial direction.
    b) For high operating pressures we would prefer pneumatic over hydraulic systems
    [x] Justification: Hydraulic systems are designed for high pressure applications.
    c) Pneumatic systems are normally quicker than hydraulic systems
    [v] Justification: Indeed, the lower viscosity of gases allows us to design mechanical systems with faster fluid expansion than with liquids.
    d) Gears having teeth without involute profile shape can be used in the design of certain types of pumps

[v] Justification: Indeed, you must be surprised of this!!, there are different types of teeth used in gear pump design, such as external gear pumps with lobes or crescents.

e) The slider-crank mechanism can be used for the design of both pumps and compressors

[v] Justification: Indeed, we studied the reciprocating piston pump and the reciprocating compressor (piston).

15. Select only the options that are **TRUE** regarding gears (Select all that apply):

a) Gears can transfer rotational motion between shafts placed in any angles from parallel to perpendicular

[v] Justification: Although parallel and perpendicular configurations are the most common. In principle, bevel gears can be designed with different cone angles, giving us a very wide range of possible angles between shafts.

b) The involute is the only shape of teeth profile that will ensure a constant acceleration (non-null) between teeth in contact

[x] Justification: No, the fundamental principle of gears is constant speed when the teeth are conjugated. Consequently, acceleration will be constant but zero.

c) Two meshing gears will always have the same circular pitch but not necessarily the same module

[x] Justification: No, according to their definition, circular pitch of two meshing gears must be the same!

d) The number of teeth of two meshing gears should not have common factors

[v] Justification : Exactly, otherwise, premature wear exists between certain teeth of the two gears, which will touch each other every time they turn.

e) Herringbone gears were invented to solve the problem of radial forces that appear in meshing of gears with straight teeth

[x] Justification: No, they were invented to solve the problem of axial forces found with helical gears.