2.72 Elements of Mechanical Design
Spring 2009

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Elements of Mechanical Design

Lecture 06: Constraints

Schedule and reading assignment

Quiz

- Quiz – HTMs

Topics

- Principles of exact constraint
- Bearing layout exercises
- Spindle shaft constraint/bearing layout

Reading assignment

- Chapter 11 in Shigley and Mischke
  - *Read sections 11.1 – 11.6, 11.9*
  - *Skim sections 11.7 – 11.8, 11.10 – 11.12*

- This is 40ish pages, but most of it is pictures/graphs/examples

Principles of exact constraint

Under, exact and over constraint

Constraints are fundamental to mechanical design

- A mechanical designers goal is to control, i.e. to constrain, parts so that they are where they are supposed to be.

Exact constraint:

- There should be one constraint for each degree-of-freedom that is constrained.

Under constraint

- Too few constraints, part is not held in all the directions it needs to be

Over constraint

- Too many constraints, some constraints may fight each other when trying to do the same job.

Mechanical constraints

We want to learn how to model and design each

We first need to know:

- How they should be used
- What their functional requirements are

How they should be used and their FRs depend upon:

- How they are laid out
- Dos and don’ts

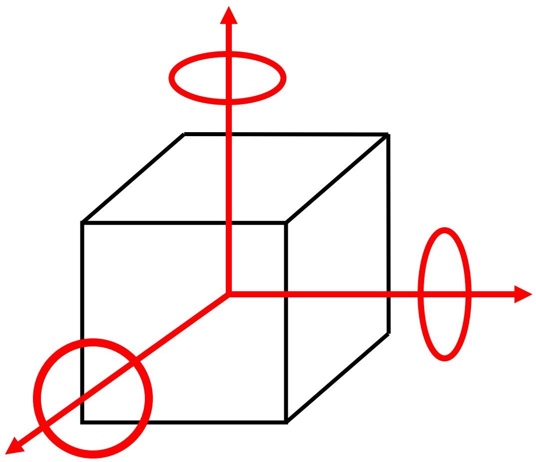
Learn to lay them out right

- Use this to obtain their Functional Requirements
- Then do the detailed design of each

Constraints and Degrees-of-freedom

Rigid components have 6 degrees-of-freedom

We will represent an ideal constraint as a line



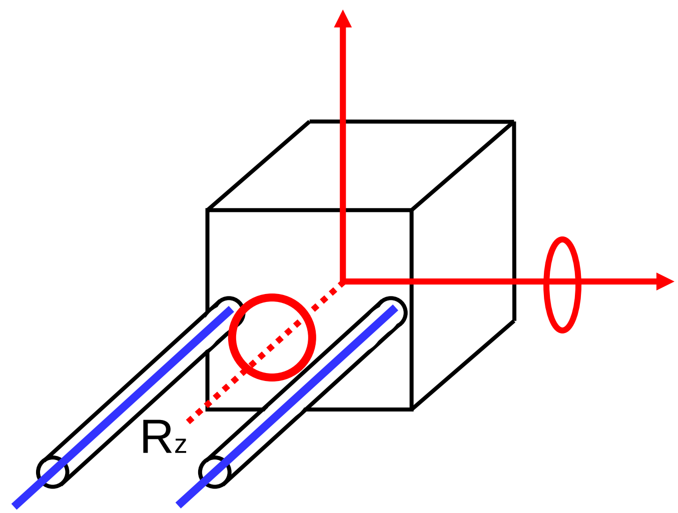
$$\boxed{6 - C = R}$$

C = # of Non-Redundant Constraints

R = # of Independent Degrees of Freedom

Example:

6 - 2constraints = 4DoFs

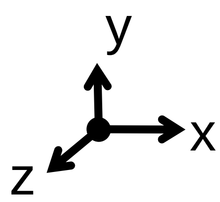


Courtesy John Hopkins, MIT

Constraints, compliance and motion

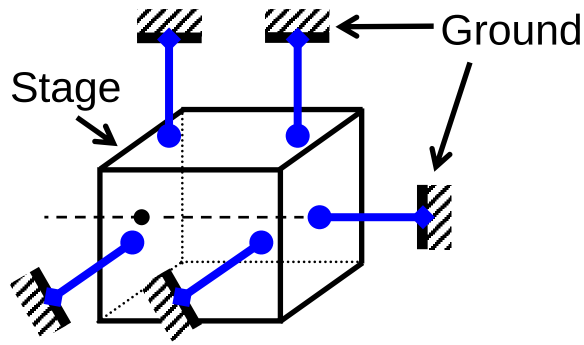
Exact constraint: Achieve desired motion

- By applying minimum number of constraints
- Arranging constraints in correct constraint topology
- Adding constraints only when necessary



For now:

- Start with ideal constraints
- Considering small motions
- Constraints = lines



Focus on rigid stage attached to ground

- What do we mean by rigid?
- What do we mean by constraint? - Stiffness ratios

The benefits of exact constraint

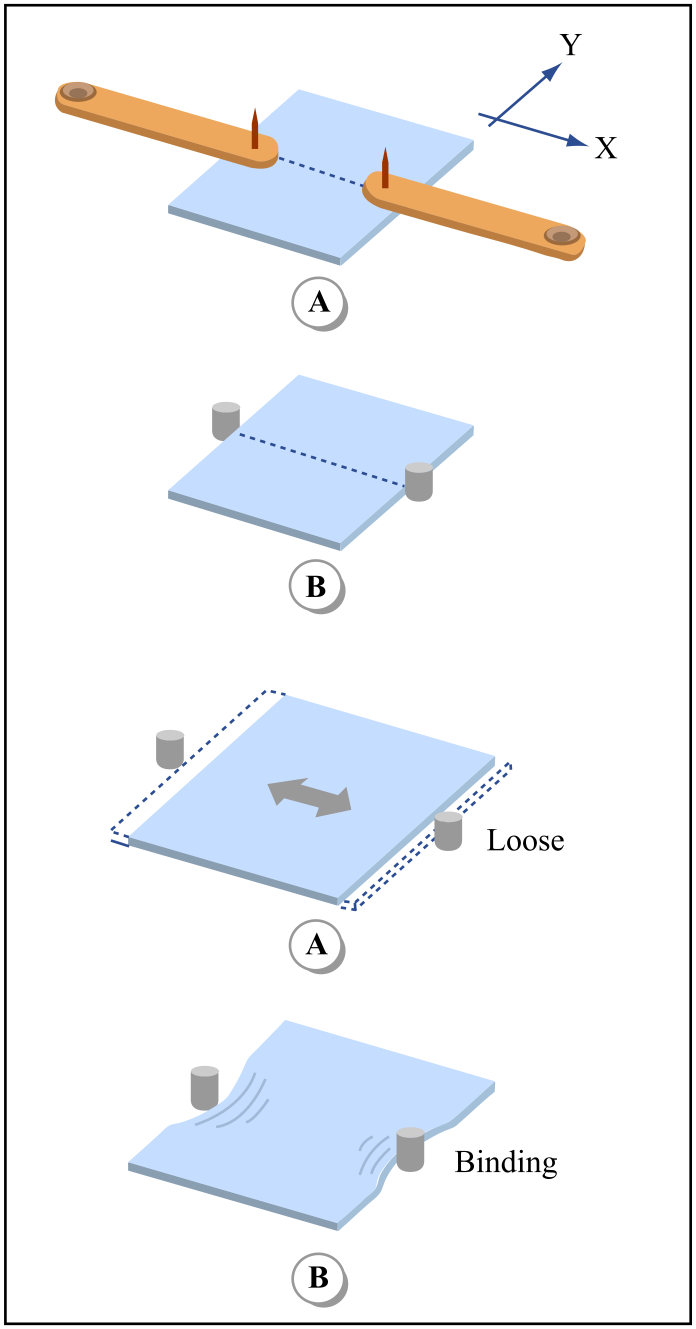


Figure by MIT OpenCourseWare.

Penalties for over constraint

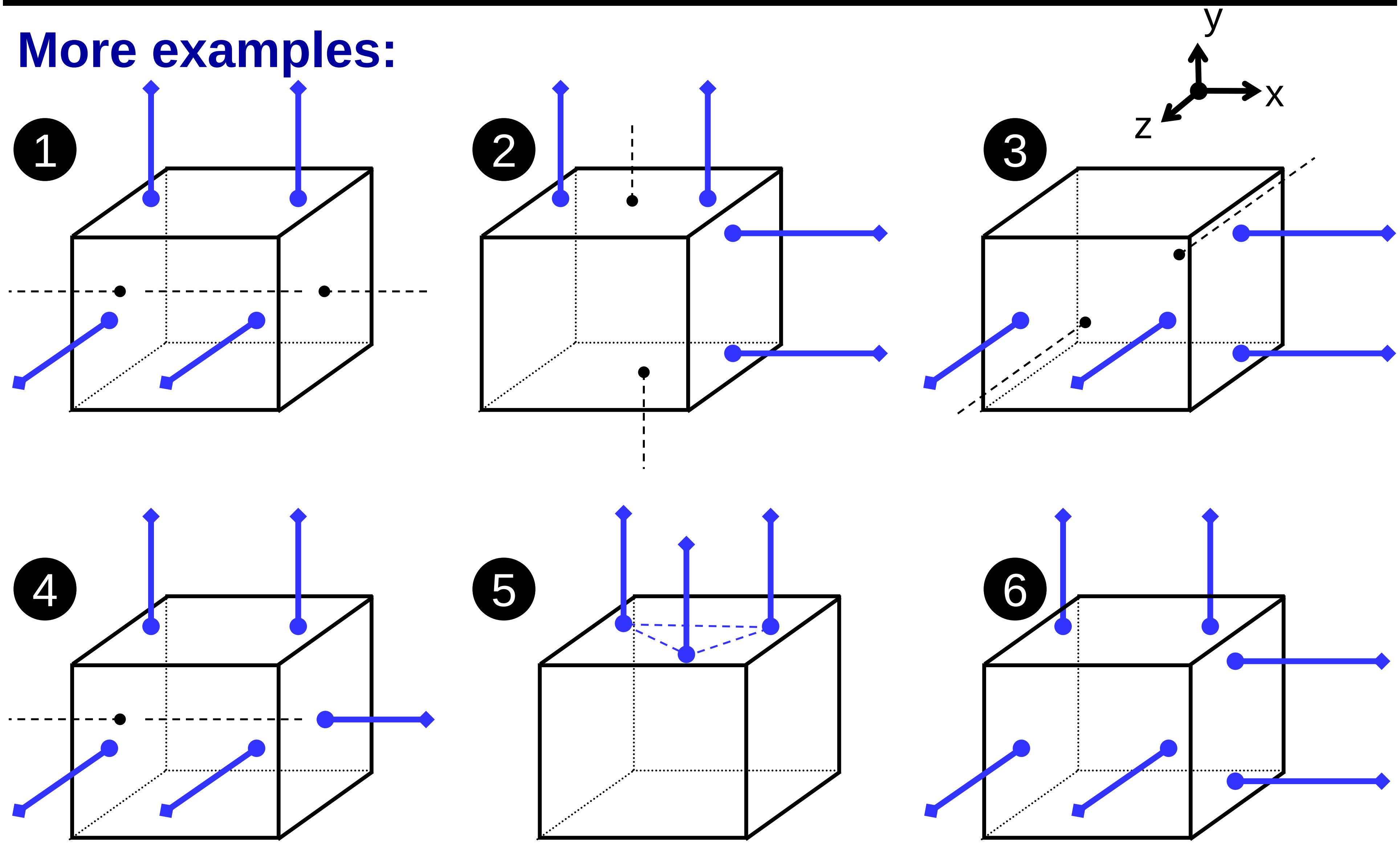
Parts of machines are now always the same strength and stiffness.

Large, stiff components have a tendency to "kill" their smaller counterparts when they are connected so that they are forced to fight.

Exact constraint design helps to prevent fights, therfore all your parts live in harmony.

Constraint examples

More examples:



Exact constraint practice

Mechanical constraints: Some bearing types

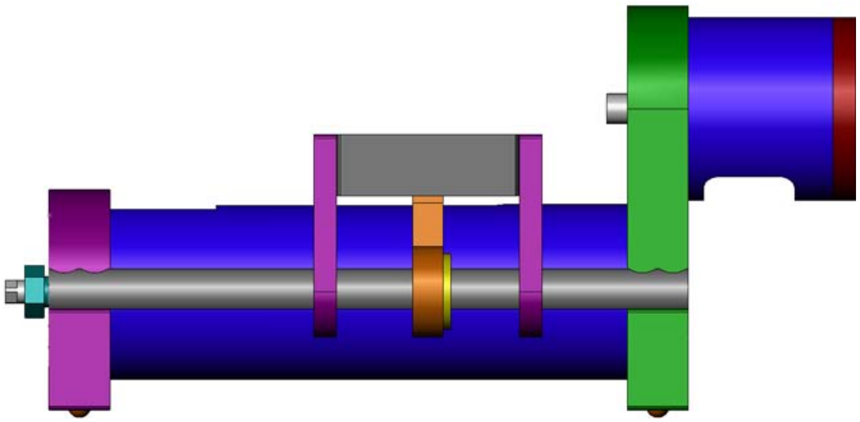
Sliding

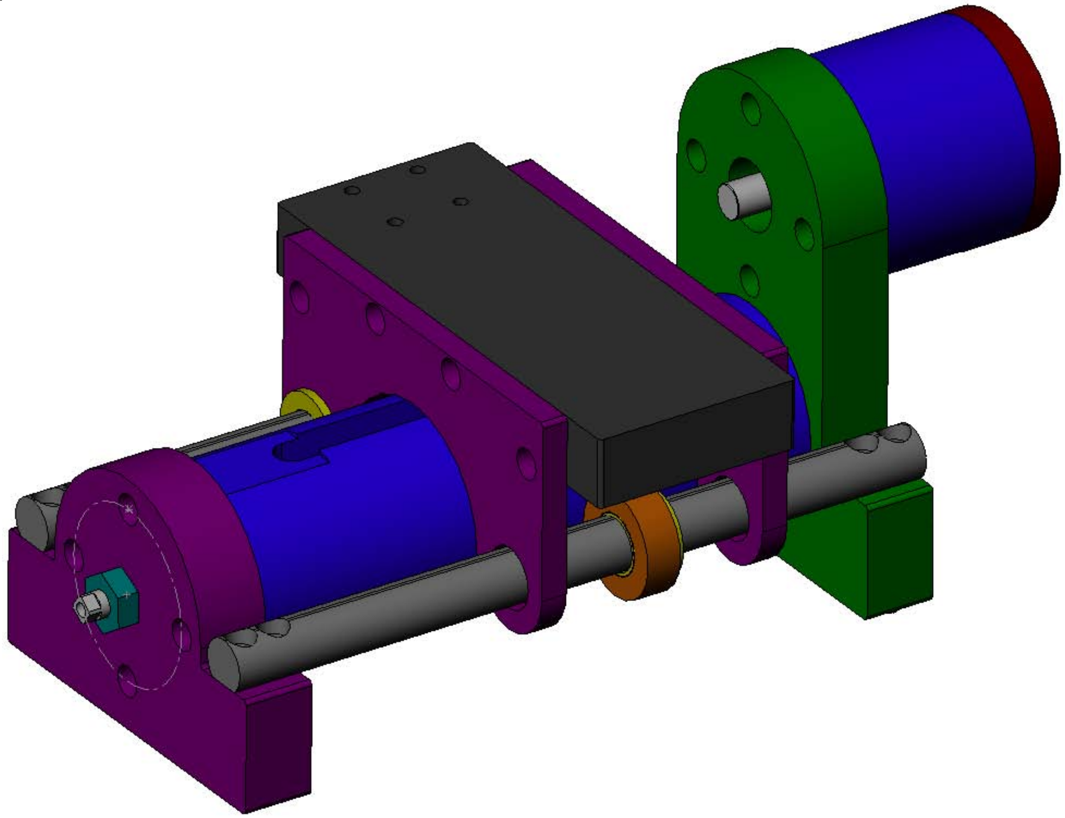
- Bushings
- etc…

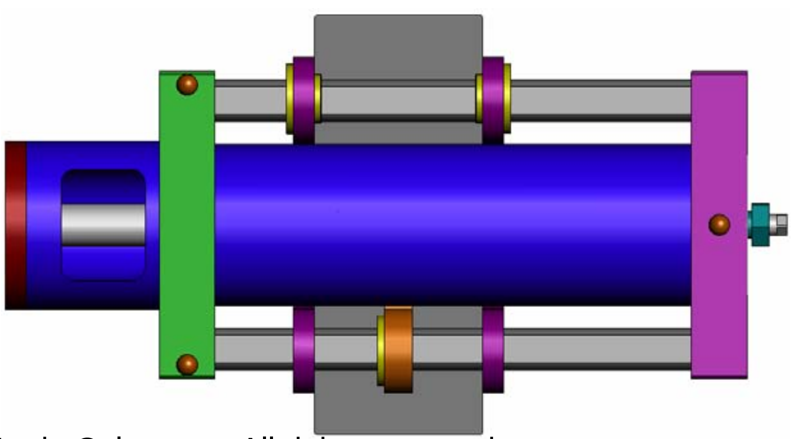
Radial rolling

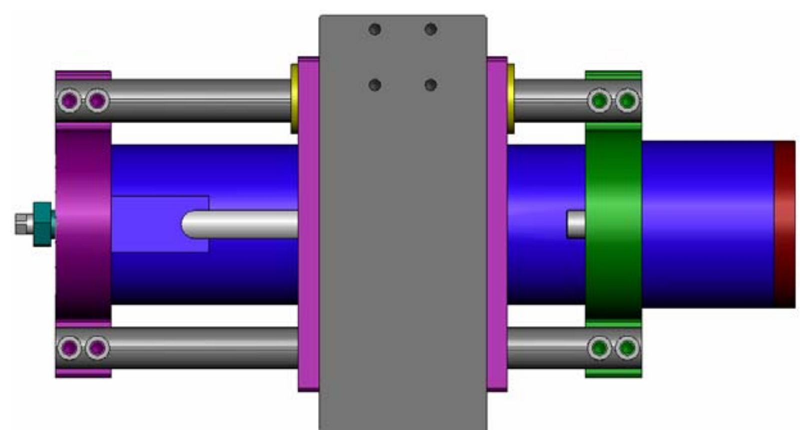
- Radial
- Shallow groove
- Deep groove (Conrad)
- Angular contact
- Tapered

Examples drawn from your lathe



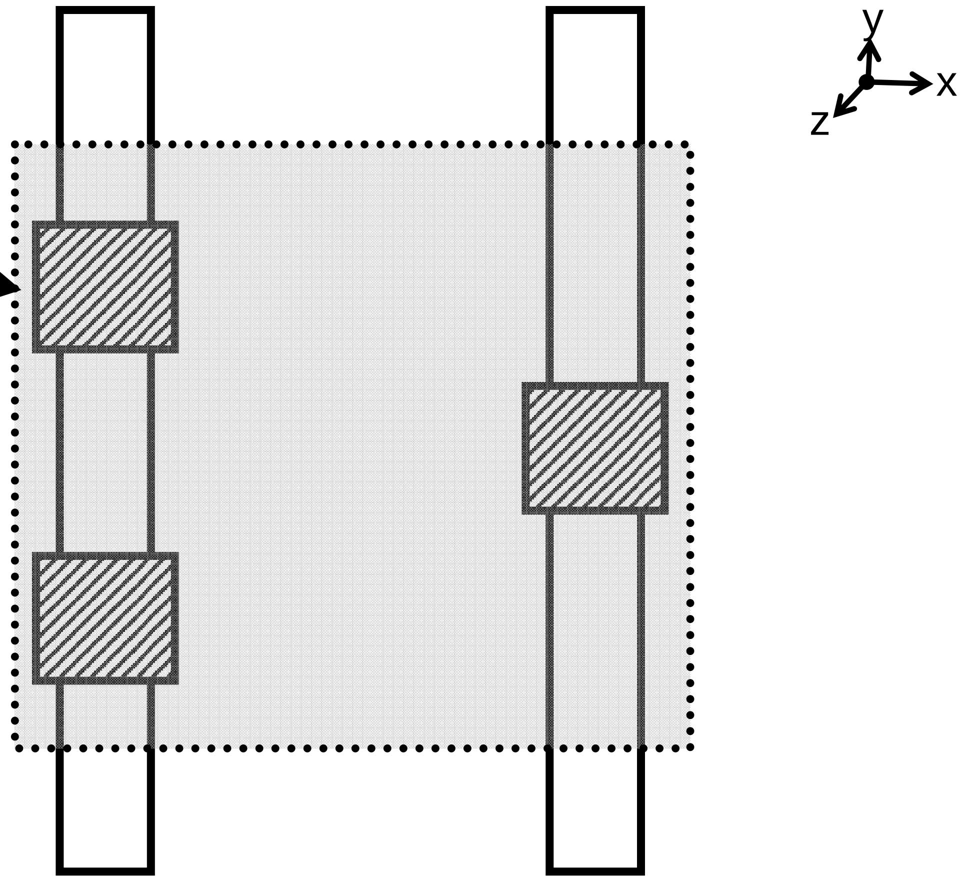




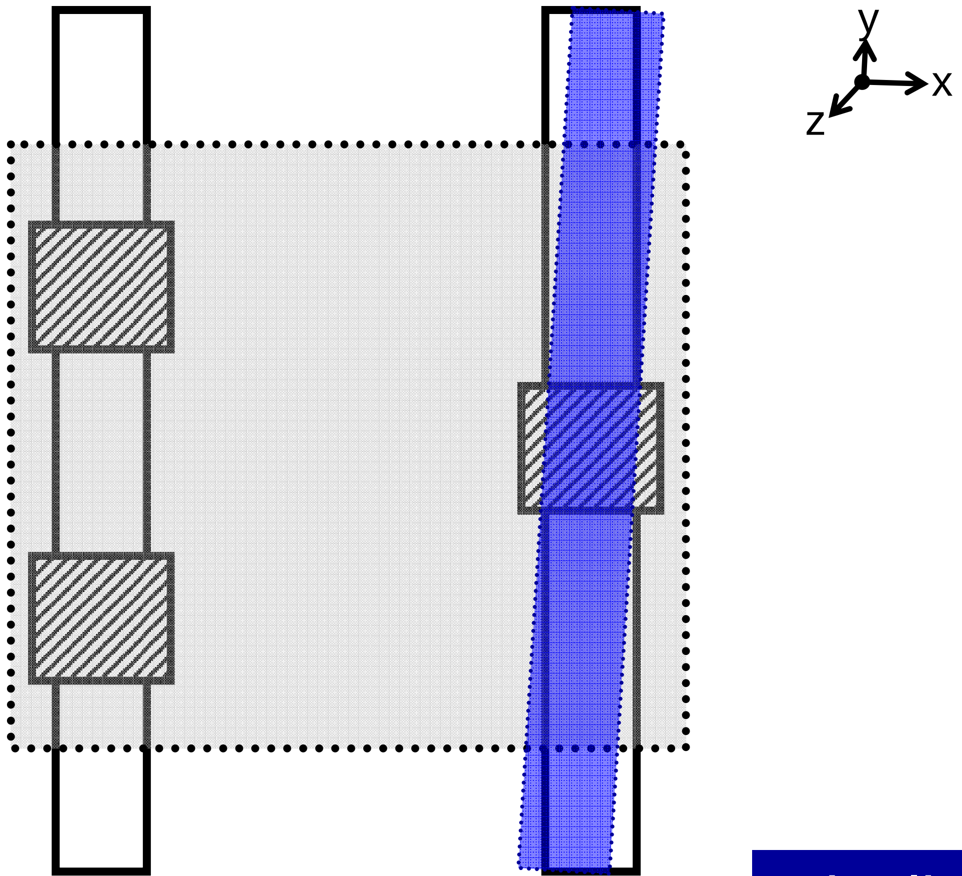


Example: Carriage constraint

Assume these are bushings as in your lathe

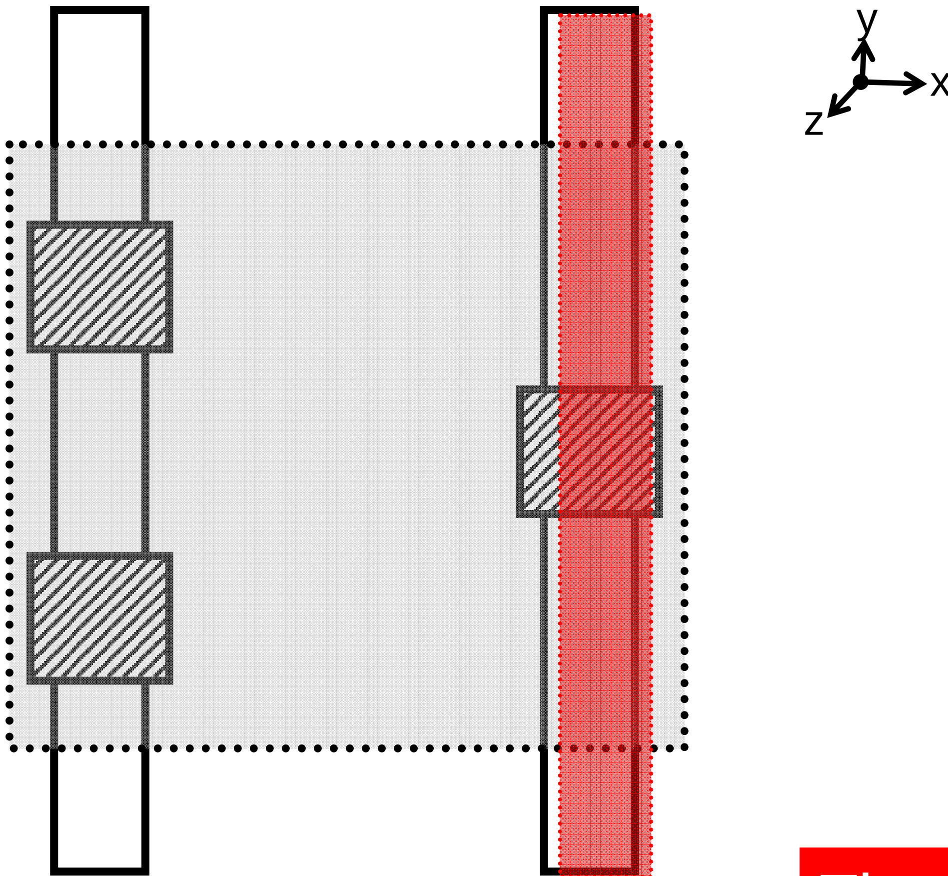


Example cont.



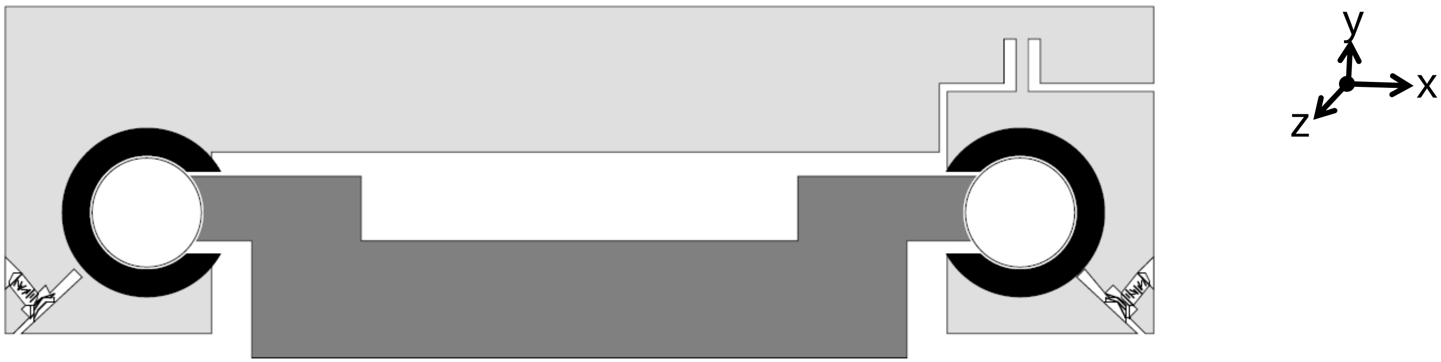
Misalignment & assembly errors

Example cont.

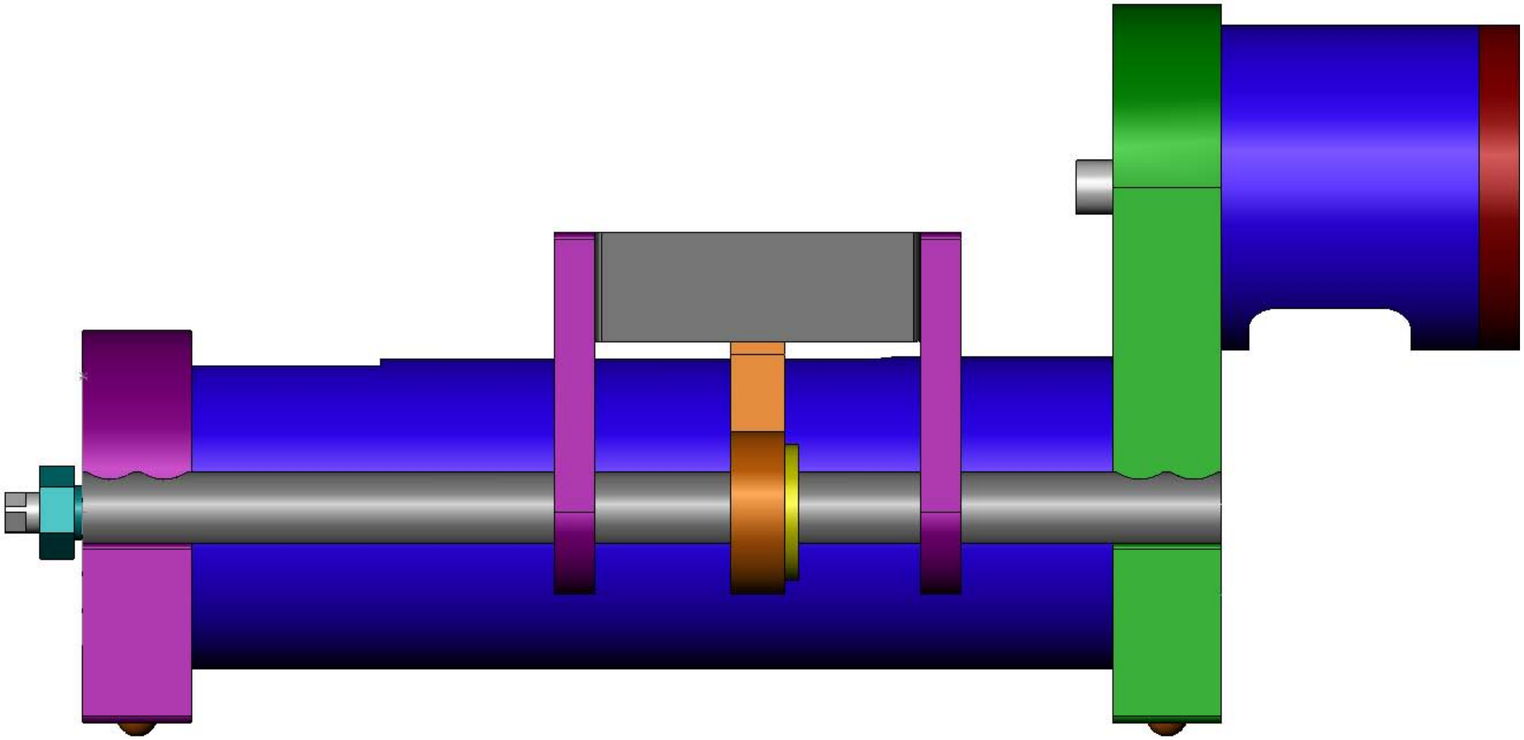


Thermally Induced growth

Practical embodiment



Flexure that is stiff in y and z, yet compliant in x



Group exercise – Carriage constraints

Identify the motions that you desire for the carriage and the minimum # of constraints that are needed to yield only these motions.

Identify the constraints from each bearing set and determine how they act in concert to yield the desired motions.

Constraint layouts
and
thermal stability

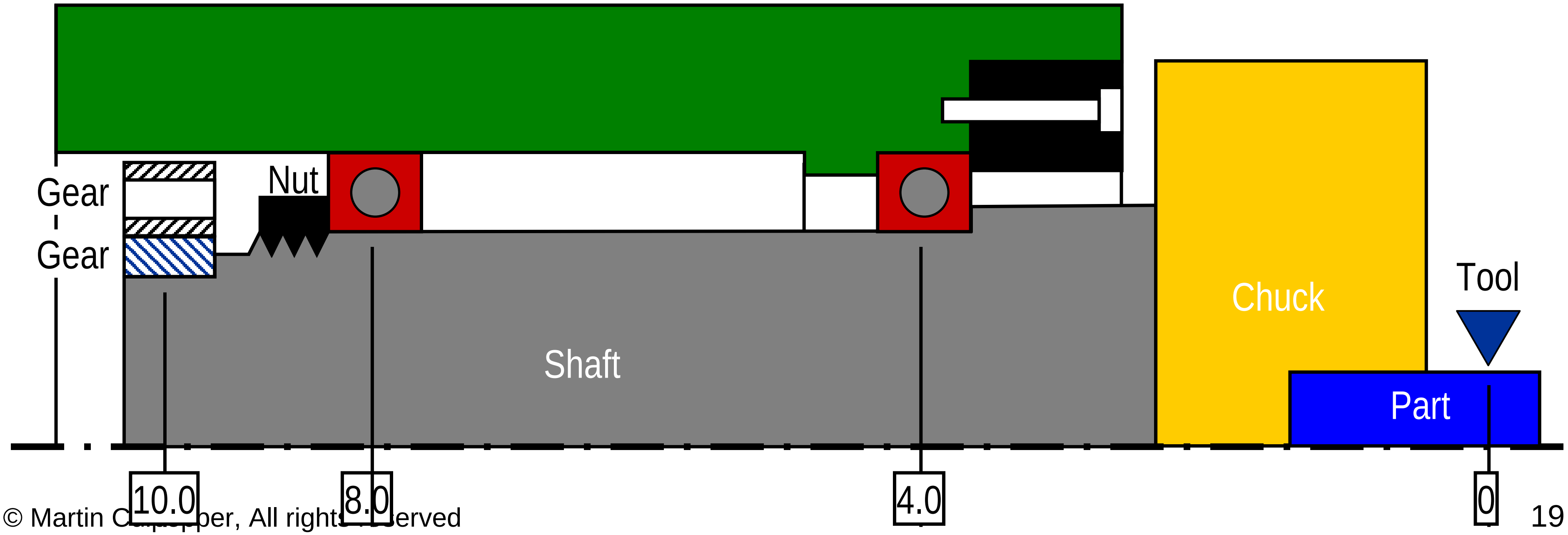
Avoiding over constraint

How to deal with the thermal growth issue

- The shaft typically gets hotter than the housing because the housing has better ability to carry heat away
- Whether the outer or inner race are fixed, matters…

Constraining front and rear bearings

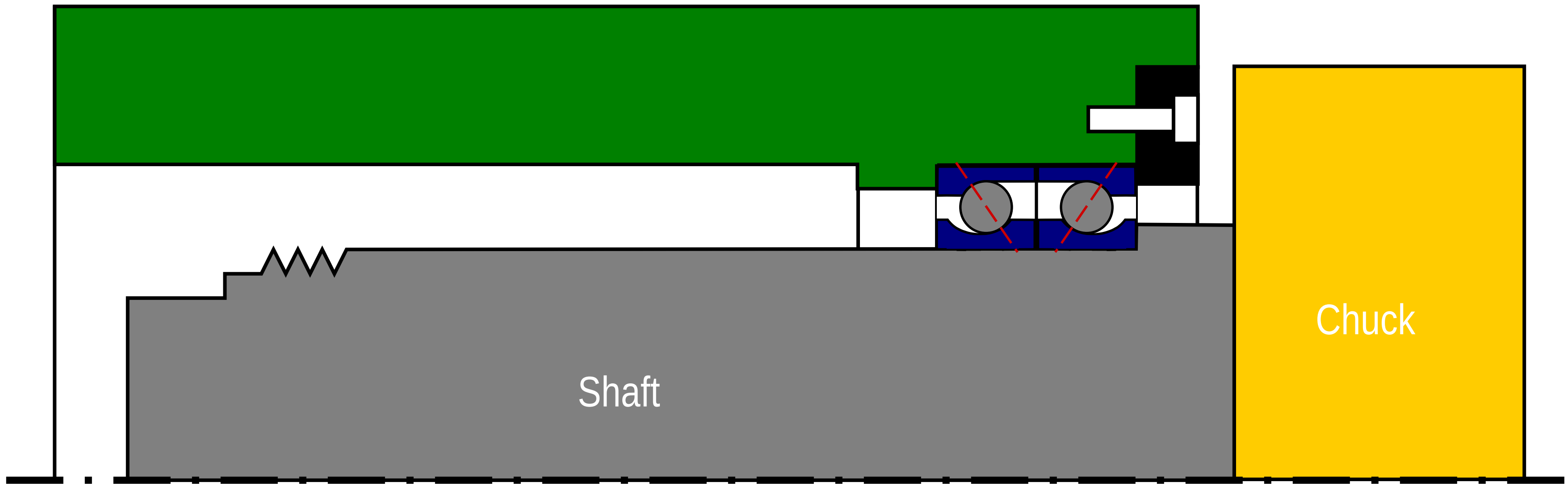
- One bearing set should be axially and radially restrained
- The other bearing set should ONLY have radial restraint

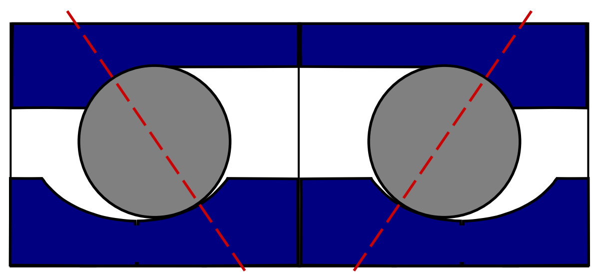


Examples: Good or bad

Outer race fixed axially, if shaft heats is this bad?

- Think about what happens to the preload…





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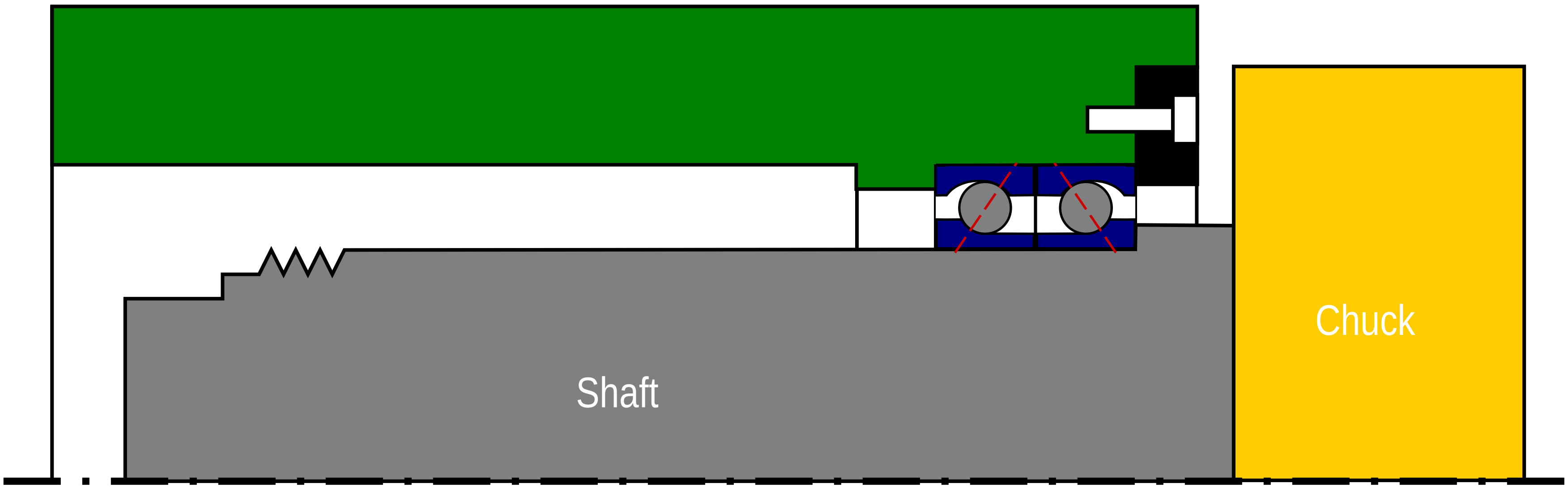
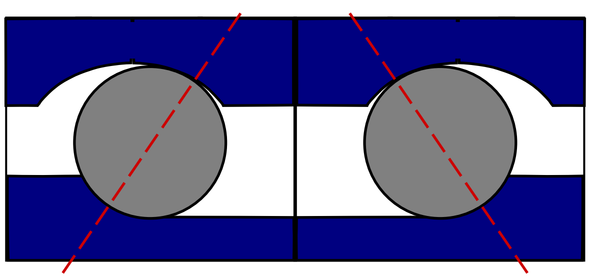


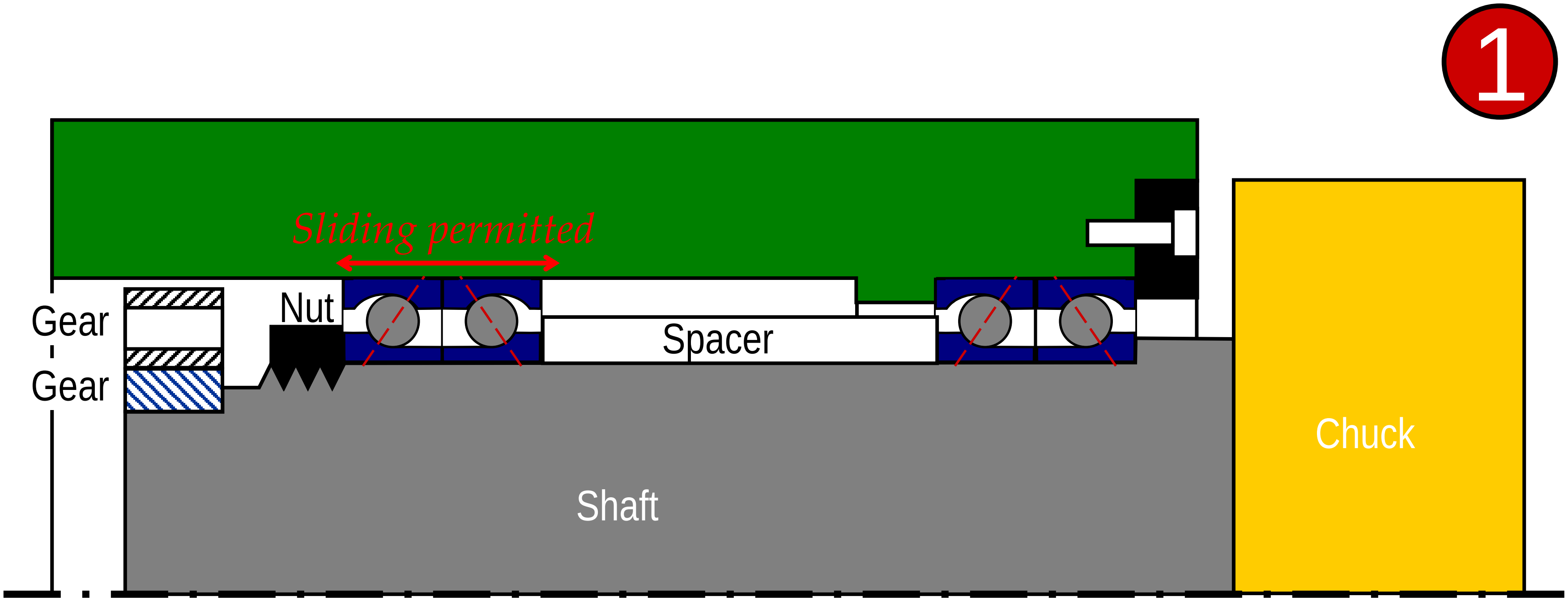


This is the back-to-back config.

It should be used when the outer race is not rotating

Examples: Good or bad

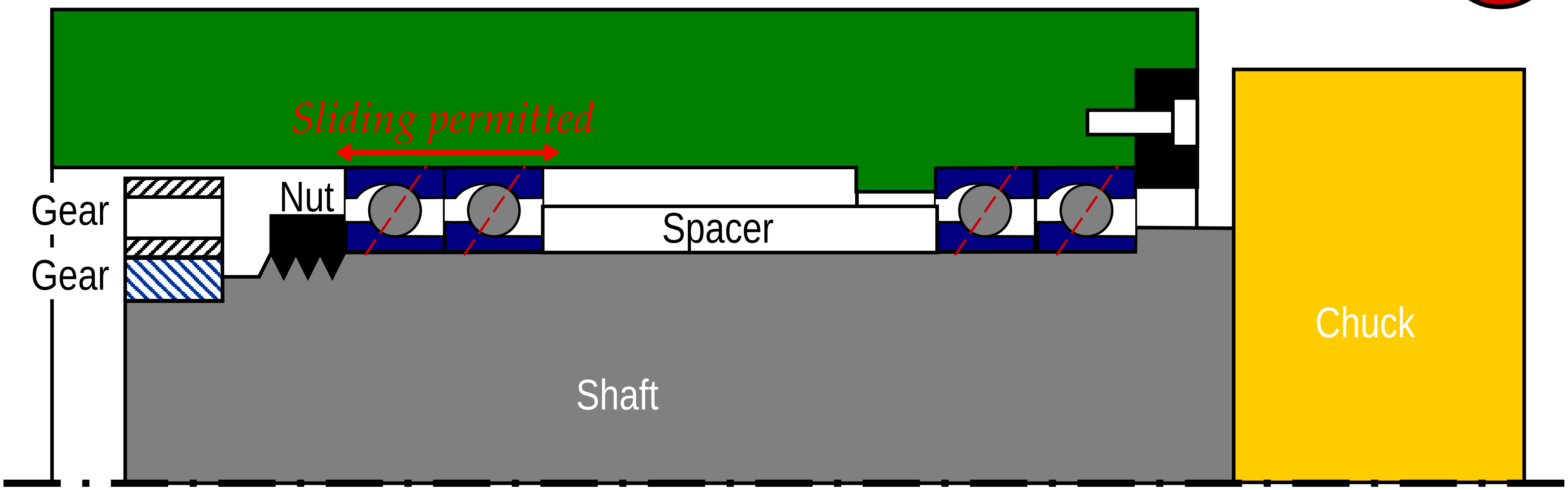
Assume the outer race does not rotate



Examples: Good or bad

Assume the outer race does not rotate

2



Examples: Good or bad

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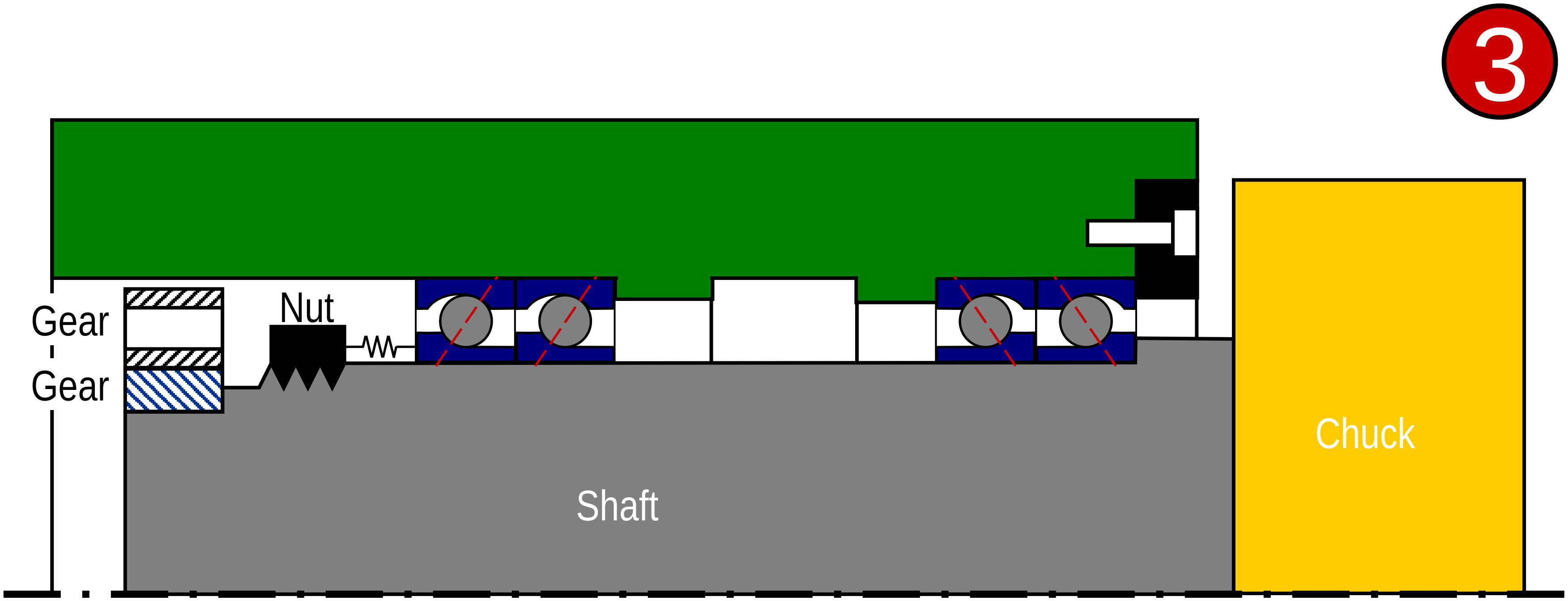
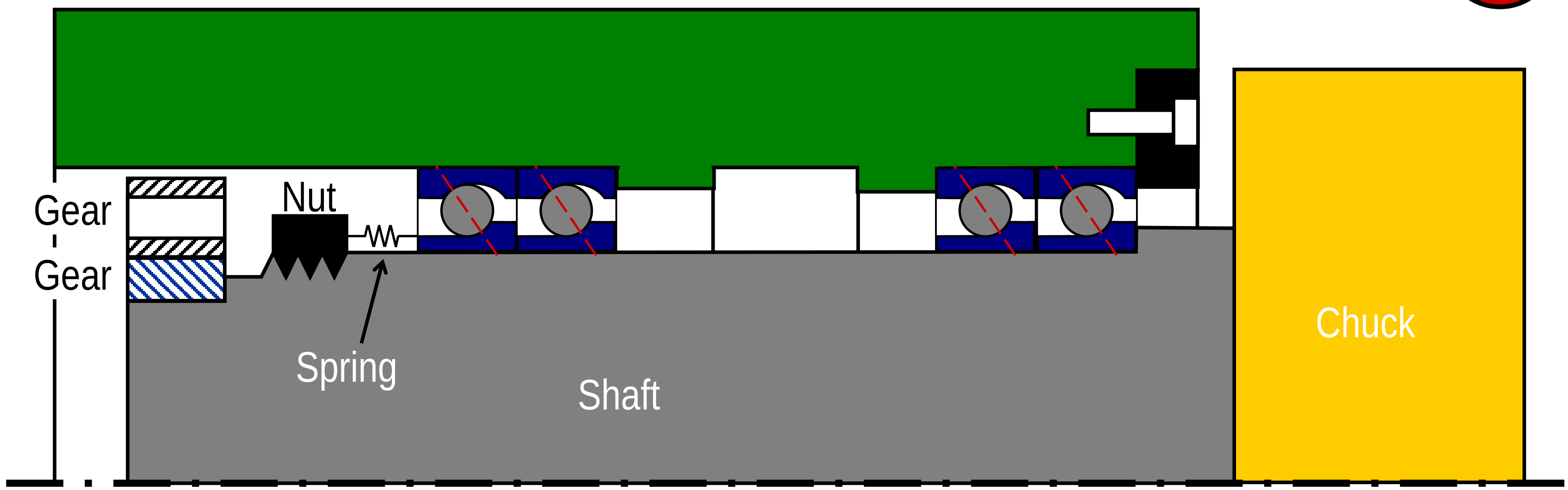


Examples: Good or bad

Assume the outer race does not rotate

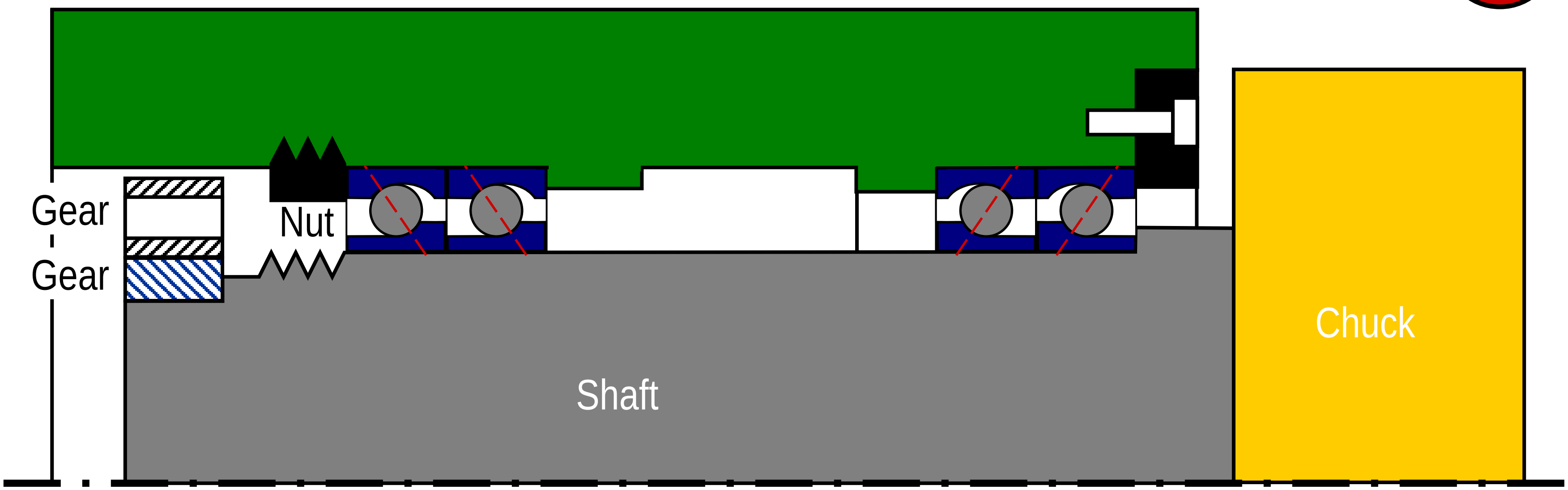
4



Examples: Good or bad

Assume the outer race does not rotate

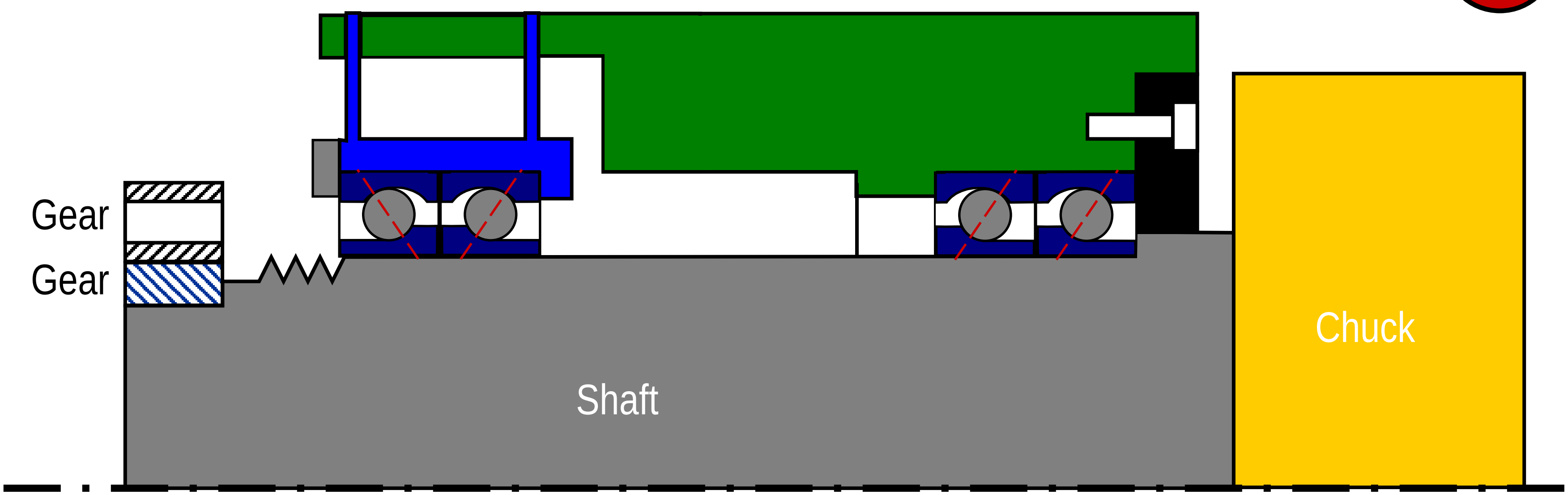
5



Examples: Good or bad

Assume the outer race does not rotate

6



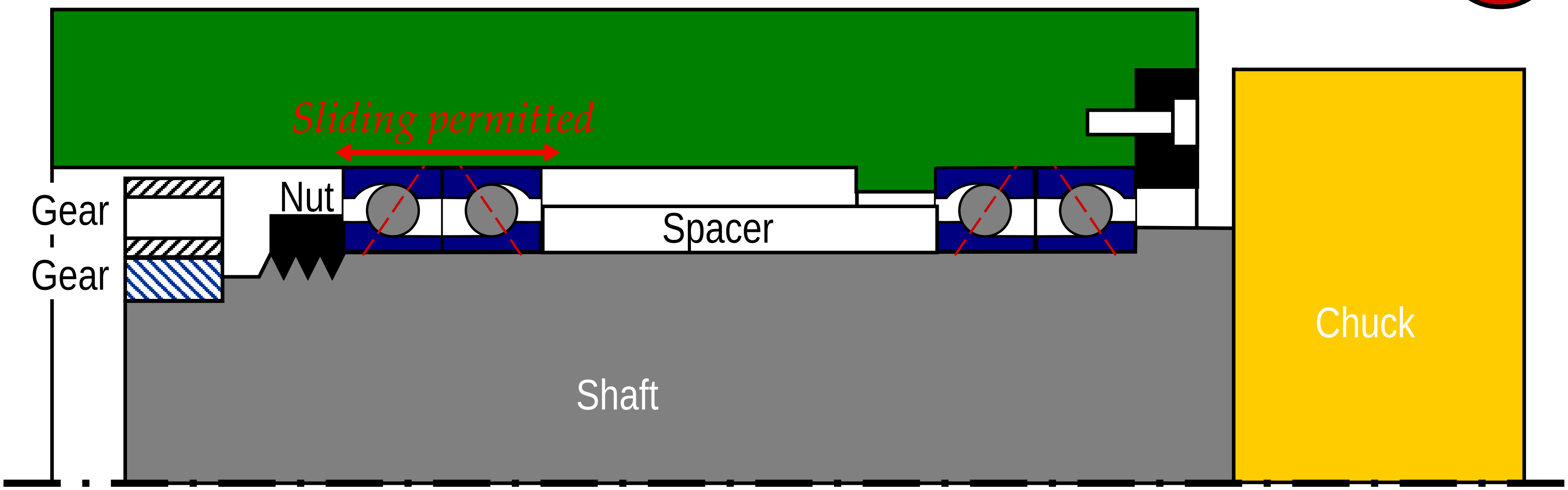
Examples: Good or bad

Assume the outer race does not rotate

Good

- Front set constrained radially and axially
- Rear set constrained only radially

1



BUT, sliding means some gap must exist and therefore one must precision fabricate if a small gap is desired

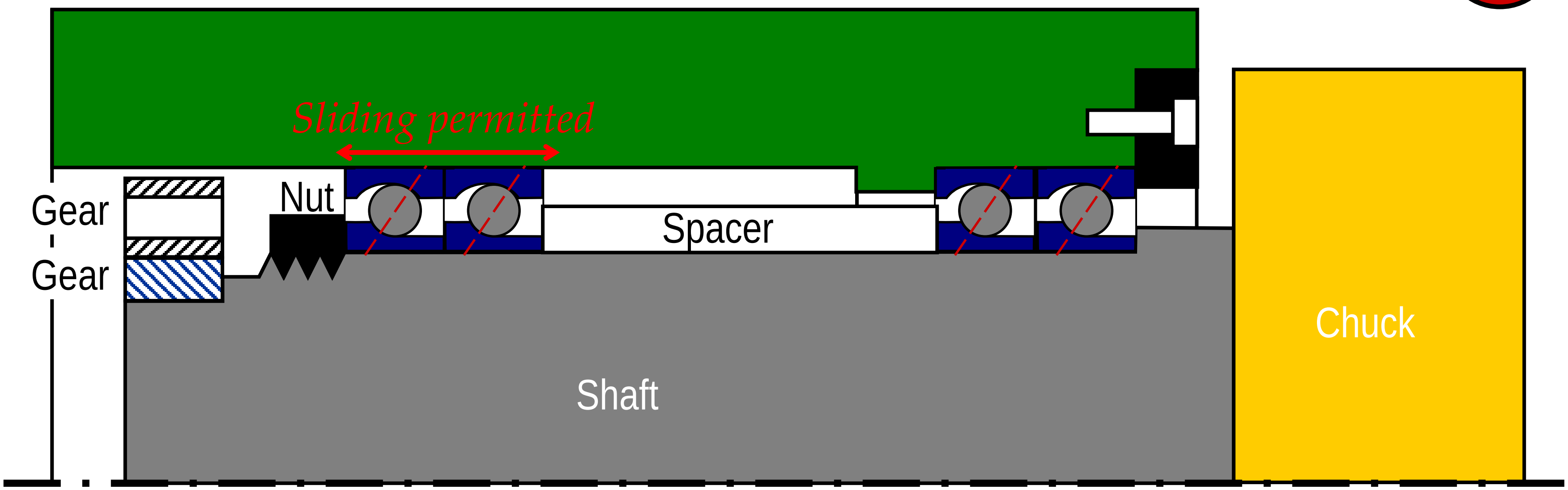
Examples: Good or bad

Bad

- Front set constrained only radially
- Rear set constrained only radially

Assume the outer race does not rotate

2



This design will not work if axial loads are to be applied along both directions

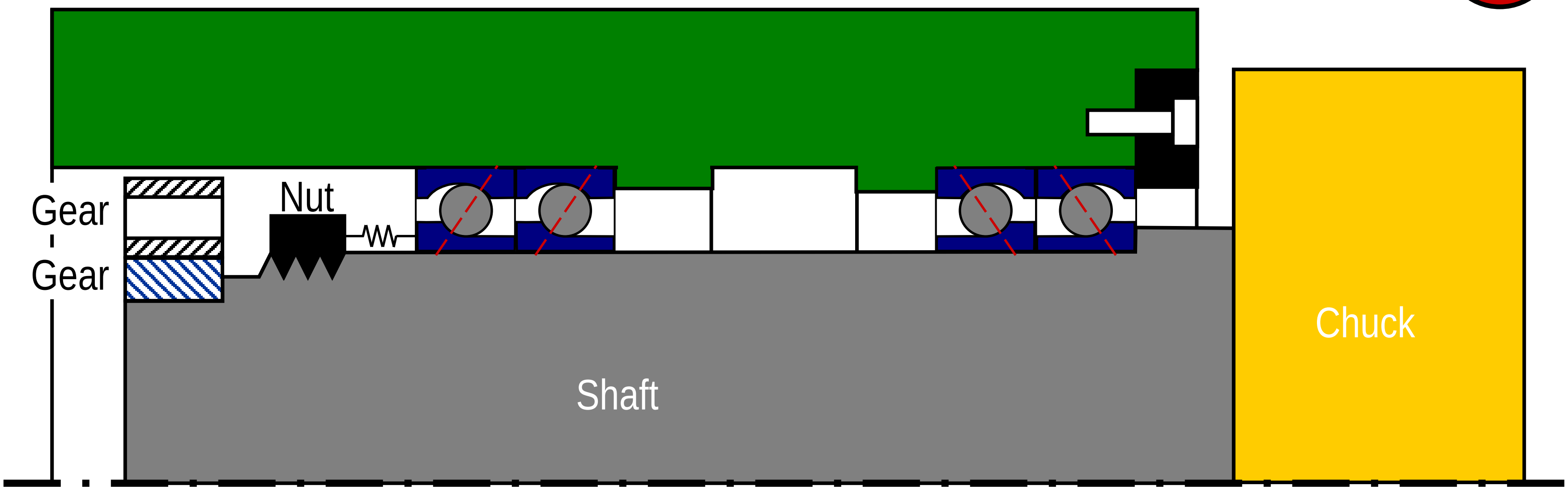
Examples: Good or bad

Good

- Front set constrained radially and ½ axially
- Rear set constrained radially and ½ axially

Assume the outer race does not rotate

3



BUT, adding a spring increases part count/cost

Axial stiffness values (left vs. right) will be different

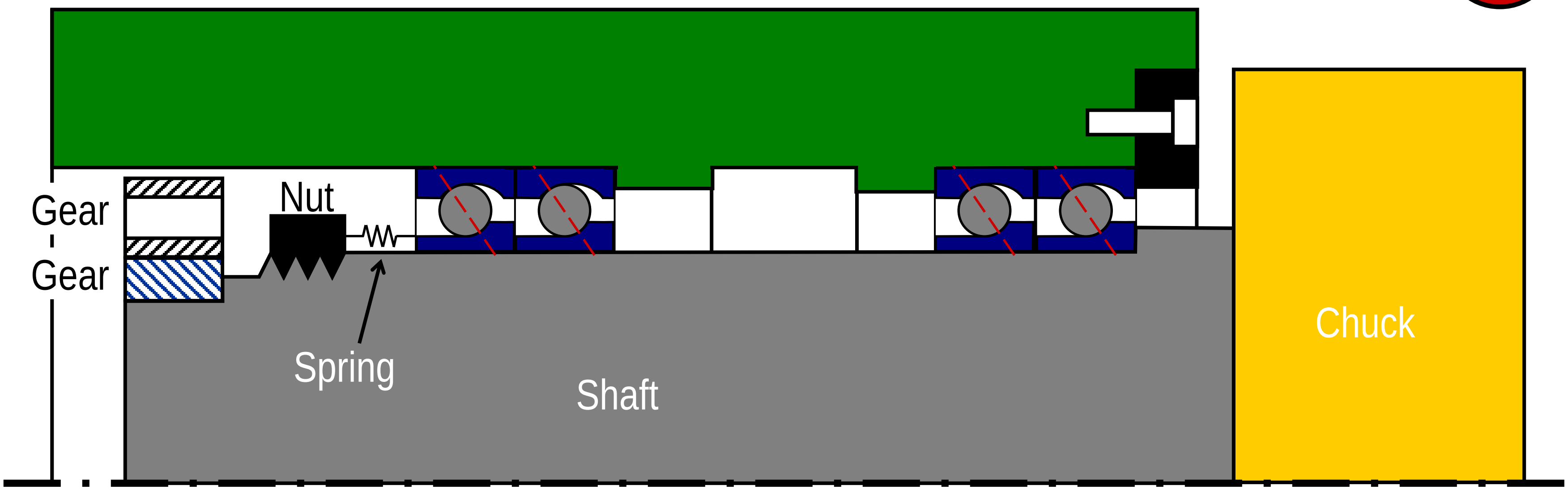
Examples: Good or bad

Assume the outer race does not rotate

BAD

- Front set is constrained only ½ axially
- Rear set is constrained only ½ axially

4



This design will not work if axial loads are to be applied along both directions

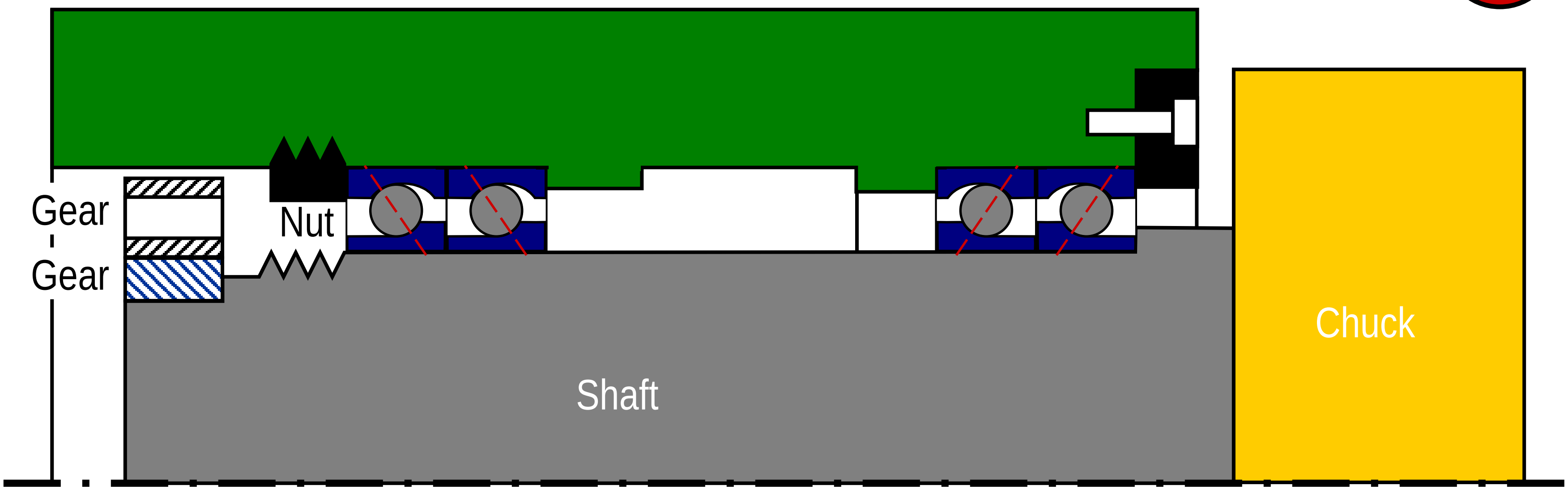
Examples: Good or bad

Assume the outer race does not rotate

BAD

- Front set is constrained ½ axially and radially
- Rear set is constrained ½ axially and radially

5



At high speeds/loads, thermal growth may kill the bearing sets

- Like a double face-to-face…

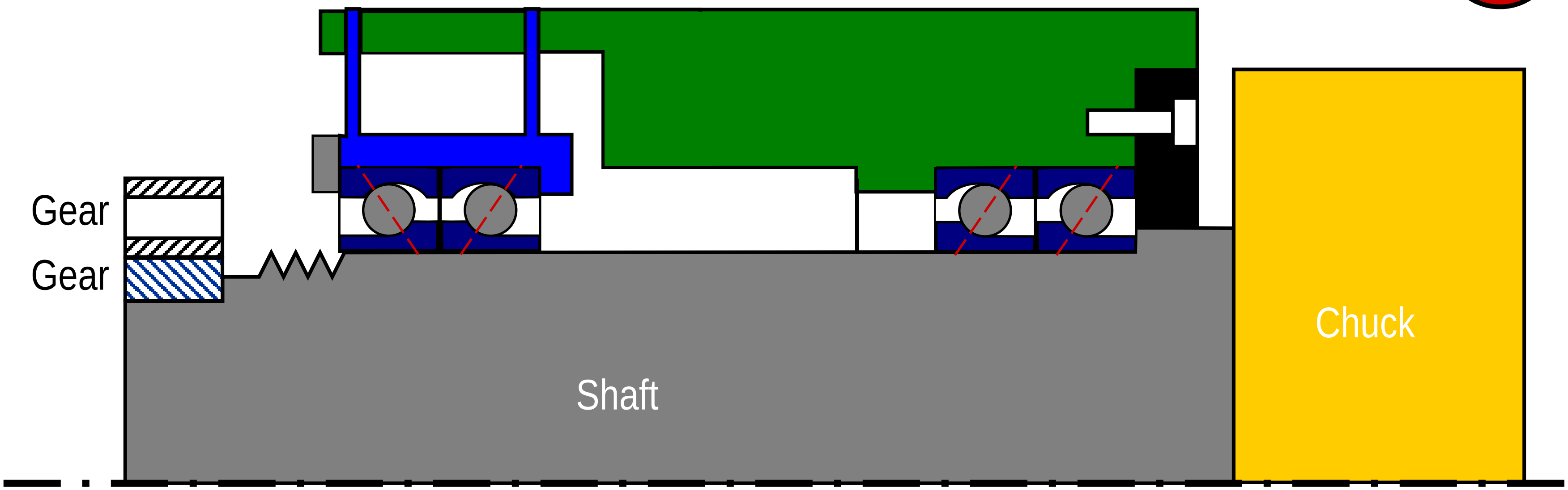
Examples: Good or bad

Bad

Assume the outer race does not rotate

- Front set constrained radially and ½ axially
- Rear set constrained radially (if flexure is of proper stiffness)

6



Left bearing set is not in the back-to-back configuration

Shaft can pop out…

Group exercise

Group exercise – Spindle constraints

The spindles you have seen use tapered roller bearings.

First, sketch a layout from one of the previous lathes and diagnose its layout

Second, generate and sketch a different way to constrain the spindle shaft.