Machine Elements

Department of Mechanical Engineering
YILDIZ TECHNICAL UNIVERSITY
Fall-2013

Week1: (16-20) September, 2013
Course contents:

1. Design concept
2. Design under dynamic loads
3. Shafts and axles
4. Shaft-Hub Joints
5. Key couplings
6. Pres fitting
7. Bolts, Nuts, Screws and Bolted Joints
8. Welded joints
9. Riveted joints
10. Brazing and adhesive joints
11. Springs
Recommended Reading

» Mechanical Engineering Design, Joseph Edward Shigley, 1986
» Design of Machinery, (Norton)
» Makine Elemanları-1, Ferhat Dikmen, Prof., Course notes
» Makine Elemanları-1, Mustafa Akkurt, Prof., 1997
» Open internet sources
Evaluation system

» Quizzes → 2 → 15%
» Homeworks → 3 → 15%
» Mid-terms → 2 → 30%
» Final → 1 → 40%

Percentage of In-Term Studies : 60%
Percentage of Final Examination : 40%
TOTAL : 100%
MACHINE DESIGN
Design is to formulate a plan for the satisfaction of the people need and to create something with a physical reality.
Example: Design of a chair

> Factors need to be considered
  + The purpose for which the chair is to be designed
  + Whether the chair is to be designed for a grown up person or a child
  + Material for the chair
    – Strength and cost need to be determined
  + Aesthetics of the designed chair.

“Chair design considers intended usage, ergonomics (how comfortable it is for the occupant), as well as non-ergonomic functional requirements such as size, stacking ability, folding ability, weight, durability, stain resistance and artistic design.”

Source: http://upload.wikimedia.org/wikipedia/commons/9/96/Vincent_Willem_van_Gogh_138.jpg
Basic concept of design

» Decision –making: every stage of design
» Consideration of different factors
» To draw certain conclusions leading to an optimum design
» Market survey to read people’s mind
» Study of existing norms

A bad decision leads to a bad design and a bad product.
Design disciplines

- Vehicle design
- Process design
- Building design
- Clothing /faction design
- Machine design
- Bridge design

»...etc.
Types of design

Development Design

Adaptive Design

New Design
Types of design based on methods

- Industrial Design
- Rational Design
- Empirical Design
Definition of a machine

» Machine is defined as a combination of resisting bodies with successfully contrained relative motions which is used to transform other forms of energy to mechanical energy or transmit and modify available energy to do some useful work.

» Machines can receive mechanical energy and modify it so that a specific task is carried out.
Machine, Device and Installation

» Transmits the mechanical power....: Machine
» Transmits the electrical signal........: Device
» Transmits the fluid.......................: Instruments

Source: www.bacamer.com
Mechanical design means the design of things of a mechanical nature, machines, products, structures, devices, and instruments. For the most part, mechanical design utilizes mathematics, the materials sciences, and the engineering mechanics sciences.

Source: Mechanical Engineering Design, Shigley, Pg:5
Machine Design

» Machine is a combination of several machine elements arranged to work together as a whole to accomplish specific purposes.

» Machine design involves designing the elements and arranging them optimally to obtain some useful work.
The phases of design

1. Recognition of need
2. Definition of problem
3. Synthesis
4. Analysis and optimization
5. Evaluation
6. Presentation

(iteration)
The phasis of design

» Recognition and Identification

The process starts, when an engineer recognizes a problem and decides to do something about it.

This often constitute a highly creative act, because the need may be only a vague discontent, a feeling of uneasiness, or a sensing that something is wrong.

Mostly sensitive people feel this and take action.

Example:
The phasis of design (continued…)

» In terms of definition of a problem; for the designed object, a black box can be considered.

Thus, we must specify the inputs and outputs of the box together with their characteristics and limitations. (Specification define the cost, the number to be manufactured, the expected life, the range, the operation temperature and the reliability.)
The phasis of design (continued...)

» For synthesis of the optimum solution:
   > This cannot take place without both analysis and optimization.
   > The desing is an iterative process and we have to do it and do it again till we get the satisfied answer.

» Evaluation and presentation
   > It is a final proof of a succesful desing and usually involves the testing of a prototype in the laboratory.
   > We need communication in three means: written, oral and graphical forms.
Reliability in machine design

- Reliability of a designed machine is concerned with the proper functioning of the elements and the machine as a whole so that the machine does not fail in use within its designed life.

- Overall safe design approach at every stage of the design is needed.
Factors to be considered in machine design

» What device or mechanism to be used?
  > To decide the relative arrangement of the constituent elements.
» Material
» Forces on the elements
» Size, shape and space requirements
» Weight of the product
» The method of manufacturing the components and their assembly
» How will it operate?
» Reliability and safety aspects
» Insepectibility
» Maintenance, cost and aesthetics of the designed product.
As a summary: The steps to be followed by a designer

» Machine design requires a thorough knowledge of engineering science in its totality along with a clear decision making capability.

» Every designer follows his own methodology based on experience and analysis.
Factors of Safety

» The term of factor safety is applied to the factor used to evaluate the safeness of a member.

\[ n = \frac{F_u}{F} \]

Where;

- \(n\) = Safety factor
- \(F_u\) = Ultimate force
- \(F\) = Force or a twisting moment, a bending moment, a slope, a deflection or some kind of distortion
Factors of Safety (Continued...)

» Buildings commonly use a factor of safety of 2.0 for each structural member. (The value for buildings is relatively low because the loads are well understood and most structures are redundant.)

» Automobiles use 3.0, and aircraft and spacecraft use 1.2 to 3.0 depending on the application and materials.

» Ductile, metallic materials tend to use the lower value while brittle materials use the higher values.

» The field of aerospace engineering uses generally lower design factors because the costs associated with structural weight are high (i.e. an aircraft with an overall safety factor of 5 would probably be too heavy to get off the ground).
ABSOLUTE SAFETY IS IMPOSSIBLE TO OBTAIN!
Codes and Standards

» Imagine no standards at all.
  > “COST AND INEFFICIENCY”

» A standard is a set of specifications for parts, materials, or processes intended too achieve uniformity, efficiency, and a specified quality.
  > One of the important purposes of standards is to place a limit on the number of items in the specifications so as to provide a reasonable inventory of tooling, sizes, shapes and varieties.

» A code is a set of specifications for the analysis, design, manufacture, and construction of something.
  > The purpose of a code is to achieve a specified degree of safety, efficiency, and performance or quality.
<table>
<thead>
<tr>
<th>Country</th>
<th>Code/Standard</th>
<th>Full name</th>
</tr>
</thead>
<tbody>
<tr>
<td>TURKEY</td>
<td>TSE</td>
<td>Türk Standartları Enstitüsü</td>
</tr>
<tr>
<td>USA</td>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>USA</td>
<td>ASME</td>
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<tr>
<td>ASM</td>
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<td>USA</td>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
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<tr>
<td>Germany</td>
<td>DIN</td>
<td>Deutsches Institut für Normung</td>
</tr>
<tr>
<td>ISO</td>
<td></td>
<td>International Standards Organization</td>
</tr>
</tbody>
</table>
Economics

The consideration of cost plays an important role in decision process that one could spend as much time in studying the cost design factor as in the study of design itself.

We can consider two simple rules:

(Observe that nothing can be said in an absolute sense concerning costs. Materials and labor show an increasing cost from year to year. )

- **Standard sizes**: The use of standard or stock sizes is a first principle of cost reduction.
- **Large tolerances**: Among the effects of design specifications on costs, those of tolerances are most significant. Tolerances in design influence the producibility of the end product.
Units

DESIGN AND MANUFACTURING
Limit Systems

• Hole and shaft are machined and here machining refers to basic size and whenever there is coincidence over the zero line, it makes problem and all the deviations are measured always respect to the zero line.

• Bilateral: if the shaft diameter has both upper and lower tolerances.
• For unilateral: no lower tolerances but upper tolerances.
» Hole basis dimensions: We consider the dimensions of the hole as the reference basis of the measurement.

» Shaft basis dimensions: Vice versa

» WE USE HOLE BASIS DIMENSIONS because of making a hole always have a more chance to fix size compared to the shaft.
clearance fit

interference fit

Transition fit
Tolerances

» **Basic size**: the nominal diameter of the shaft (or bolt) and the hole. This is, in general, the same for both components.

» **Lower deviation**: the difference between the minimum possible component size and the basic size.

» **Upper deviation**: the difference between the maximum possible component size and the basic size.

» **Fundamental deviation**: the minimum difference in size between a component and the basic size. This is identical to the upper deviation for shafts and the lower deviation for holes. If the fundamental deviation is greater than zero, the bolt will always be smaller than the basic size and the hole will always be wider. Fundamental deviation is a form of allowance, rather than tolerance.

» **International Tolerance grade**: this is a standardized measure of the maximum difference in size between the component and the basic size (see below).
Limit System

» **Standard Tolerances:**
   18 grades: It01, IT0 and IT1-1T16

» **Fundamental deviations:**
   25 types: A-ZC (For holes)
   a-zc (For shafts)

Example: 50H6/g5
- 50...Nominal size
- H.....Hole basis
- g5...(Fundamental deviation, standard tolerances
Shaping

Joining

Machining

Surface finishing

Non-conventional

Heat -Treatment
Casting  
Forging  
Extrusion  
Rolling
Machining

Turning

Milling

Stamping

Drilling
Joining

Welding

Brazing

Riveting

Screw fastening
ENGINEERING MATERIALS
Engineering Materials

Industrial Use of Materials

"If man began with speech, and civilization with agriculture, industry began with fire. Man did not invent it, probably nature produced the marvel for him...He put the wonder to a thousand uses. First, perhaps... to conquer his fearsome enemy, the dark; then...for warmth,...then he applied it to metals, tempering them, and combining them into stronger and suppler than those in which they had come to his hand...“

Source: http://telstar.ote.cmu.edu/environ/m3/s4/matindususe.shtml
Choice of materials for a machine element

» Properties of the material
» Cost
» Availability
Example: Material understanding of Mechanical parts of sensors

Important properties
- Low moisture
- Excellent abrasion resistance
- Availability in all colors
- Low coefficient of friction
- Light material
- Less cost
- High heat resistance
- Good moulding properties
- ...etc

Figure: Inductive sensor
Common Engineering Materials

- Ferrous Materials
- Non-metals (Glass, ceramics ...etc.)
- Unferrous materials

Important mechanical Properties
Important ferrous metals

1. Cast iron
2. Wrought iron
3. Steel
1. Cast iron

- Alloy of iron, carbon and silicon
- Hard and brittle
- Carbon content within 1.7% to 3%
- Carbon presence free carbon / iron carbide Fe₃C

Types of cast iron:

a) Grey cast iron
b) White cast iron
c) Malleable cast iron
d) Spheroidal or nodular cast iron
e) Austenitic cast iron
f) Abrasion resistant cast iron
a) Grey cast iron

» Carbon here is mainly in the form of graphite. This type of cast iron is inexpensive and has high compressive strength. Graphite is an excellent solid lubricant and this makes it easily machinable but brittle.

Grey cast iron
> FG20, FG35 or FG35Si15
+ The numbers indicate ultimate tensile strength in MPa and 15 indicates 0.15% silicon.

Figure: Motor block
b) White cast iron

- In these cast irons carbon is present in the form of iron carbide (Fe₃C) which is hard and brittle.
- The presence of iron carbide increases hardness and makes it difficult to machine.
- These cast irons are abrasion resistant.

White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverisers, and the teeth of a backhoe's digging bucket (although cast medium-carbon martensitic steel is more common for this application).
c) Malleable cast iron

» These are white cast irons rendered malleable by annealing. These are tougher than grey cast iron and they can be twisted or bent without fracture.
» Excellent machining properties,
» Inexpensive
» Used for making parts where forging is expensive
» Hubs for wagon wheels, brake supports
» Designated based on the method of processing.
  > Black heart BM32, BM30
  > White heart WM42, WM35

Figure: Pipe fittings
d) Spheroidal or nodular graphite cast iron

- In these cast irons graphite is present in the form of spheres or nodules
- High tensile strength
- Good elongation properties
- Designated as: SG50/7, SG80/2 etc.
- First number gives the tensile strength in Mpa. Second number indicates percentage elongation.
e) Austenitic cast iron

» Depending on the form of graphite present, these cast iron is classified broadly under two headings.
  > Austenitic flake graphite iron, AFGNi16Cu7Cr2
  > Spheroidal/nodular graphite iron, ASGNI20Cr2

Alloy cast irons (contain in small percentages);
Silicon, manganese sulphur, phosphorus etc.

May be produced by adding alloying elements for more strength and improved properties:
Nikel, chromium, molybdenum, copper and manganese

Used for making automobile parts:
Cylinders, pistons, piston rings, brake drums etc.
f) Abrasion resistant cast iron

» These are alloy cast iron and the alloying elements render abrasion resistance

» Typical designation:
   ABR33 Ni4 Cr2

» Indicates a tensile strength in Mpa with 4% nickel and 2% chromium.
2. Wrought iron

» This is a very pure iron where the iron content is of the order of 99.5%. It is produced by remelting pig iron and some small amount of silicon, sulphur, or phosphorus may be present. It is tough, malleable and ductile and can easily be forged or welded. It cannot however take sudden shock. Chains, crane hooks, railway couplings and such other components may be made of this iron.
3. Steel

» This is by far the most important engineering material and there is an enormous variety of the steel to meet the wide variety of engineering requirements.

» Steel is basically an alloy of iron and carbon in which the carbon content can be less than 1.7% and carbon is present in the form of iron carbide to impart hardness and strength.

» Two main categories of steel:
  a) Plain carbon steel
  b) Alloy steel
a) Plain carbon steel

- The properties of plain carbon steel depend mainly on the carbon percentages. Other alloying elements are not usually present in more than 0.5 to 1%, eg. 0.5% Si or 1% Mn etc. Plain carbon steel and they are designated as C01, C14, C45, C70, where the number indicates the carbon percentage.

- Categorization of plain carbon steels:
  - Dread mild steel – upto 0.15 %C
  - Low carbon steel or mild steel- 0.15 to 0.46% C
  - Medium carbon steel- 0.45 to 0.8 %C.
  - High carbon steel – 0.8 to 1.5% C

  In general higher carbon percentage indicates higher strength.
b) Alloy steel

These are steels in which elements other than carbon are added in sufficient quantities to impart desired properties, such as wear resistance, corrosion resistance, electric or magnetic properties.

Chief alloying elements:

- Nickel: strength and toughness
- Chromium: hardness and strength
- Tungsten: hardness at elevated temperature
- Vanadium: tensile strength
- Manganese: high strength in hot rolled/hear treated condition
- Silicon: high elastic limit
- Cobalt: hardness
- Mlybdenum: extra tensile strength
Alloy steel

Some alloy steels:
35Ni1Cr60, 30Ni4Cr1, 40Cr1Mo28, 37Mn2

Stainless steel (18/8 steel):
Corrosion resistant
Chromium and nickel: 18% and 8% respectively

A typical designation of a stainless steel:
15Si2Mn2Cr18Ni8; carbon percentage is 0.15
Non-ferrous metals

» Metals containing elements other than iron as their chief constituents are usually referred to as non-ferrous metals.

» Aluminium

> This is the white metal produced from Alumina. In its pure state it is weak and soft but addition of small amounts of Cu, Mn, Si and Magnesium makes it hard and strong. It is also corrosion resistant, low weight and non-toxic.
Two forms of Aluminium:

- **Duralumin**
  - This is an alloy of 4% Cu, 0.5% Mn, 0.5% Mg and aluminium. It is widely used in automobile and aircraft components.

- **Y-alloy**
  - This is an alloy of 4% Cu, 1.5% Mn, 2% Ni, 6% Si, Mg, Fe and the rest is Al. It gives large strength at high temperature. It is used for aircraft engine parts such as cylinder heads, piston.
Magnalium

> This is an aluminum alloy with 2 to 10% magnesium. It also contains 1.75% Cu. Due to its light weight and good strength it is used for aircraft and automobile components.

Copper alloys

> Copper is one of the most widely used non-ferrous metals in industry. It is soft, malleable and ductile and is a good conductor of heat and electricity.
Bass (Cu-Zn alloy)

> It is fundamentally a binary alloy with Zn up to 50%. As Zn percentage increases, ductility increases up to 37% of Zn beyond which the ductility falls.

> Small amount of other elements viz. Lead or tin imparts other properties to brass Lead fives good machining quality and tin imparts strength. Brass is highly corrosion resistant, easily machinable and therefore a good bearing material.
Bronze (Cu-Sn alloy)

> This is mainly a copper-tin allow where tin percentage may vary between 5 to 25. It provides hardness but tin content also oxidizes resulting in brittleness. Deoxidizers such as Zn may be added.

Gun metal

> It is an alloy where 2% Zn is added as deoxidizing agent and typical composition are 88% Cu, 10% Sn 2% Zn. This is suitable for working in cold state. It was originally made for casting guns but used now for boiler fittings, bushes, glands and other such uses.
Non-metals

» Non metallic materials are used in engineering practice due to principally their low cost, flexibility and resistance to heat and electricity.

» Timber
  > This is a relatively low cost material
  > Bad conductor of heat and electricity
  > Good elastic and frictional properties

» Widely used in:
  > Foundry patterns, water lubricated bearings
» **Leather**
  > This is widely used in engineering for its flexibility and wear resistance
  > Uses: Belt drives, washers, similar applications

» **Rubber**
  > It has high modulus and is used for drive elements, sealing, vibration isolation and similar application.
Plastics

> These are synthetic materials which can be moulded into desired shapes under pressure with or without application of heat. These are now extensively used in various industrial applications for their corrosion resistance, dimensional stability and relatively low cost.

» There are two main types of plastics:
  > Thermosetting plastics
  > Thermoplastics
Thermosetting plastics

Thermosetting plastics are formed under heat and pressure. It initially softens and with increasing heat and pressure, polymerisation takes place. This results in hardening of the material. These plastics cannot be deformed or remoulded again under heat and pressure.

Some examples of thermosetting plastics

- Phenol formaldehyde (Bakelite)
- Phenol-furfural (Durite)
- Epoxy resins
- Phenollic resins
Thermoplastics

- Thermoplastics do not become hard with the application of heat and pressure and no chemical change takes place. They remain soft at elevated temperatures until they are hardened by cooling. These can be re-melted and remoulded by application of heat and pressure.

Some example of thermoplastics

- Cellulose nitrate (celluloid)
- Plythene
- Polyvinyl acetate
- Polyvinyl chloride (PVC)
MECHANICAL PROPERTIES OF ENGINEERING MATERIALS
Mechanical Properties of common engineering materials

» Elasticity

> This is the property of a material to regain its original shape after deformation when the external forces are removed. All materials are plastic to some extent but the degree varies, for example, both mild steel is more elastic than rubber.

Source: http://blog.ioanacolor.com/2011/06/elasticity/
Plasticity

This is associated with the permanent deformation of material when the stress level exceeds the yield point. Under plastic conditions materials ideally deform without any increase in stress.
Hardness

» Property of the material that enables it to resist permanent deformation, penetration, indentation etc.

» Size of indentations by various types of indenters are the measure of hardness

1. Brinnel hardness test
2. Rockwell hardness test
3. Vickers hardness (diamond pyramid test)

Tests give hardness numbers which are related to yield pressure (MPa)
The **Brinell scale** characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in **materials science**.

**Formula:**

\[
HBW = 0.102 \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})}
\]

**Where:**
- \( F \) = applied force (N)
- \( D \) = diameter of indenter (mm)
- \( d \) = diameter of indentation (mm)

**Video:**
http://www.youtube.com/watch?v=RJXJpeH78iU
Example values:

<table>
<thead>
<tr>
<th>Material</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood (e.g., pine)</td>
<td>1.6 HBS 10/100</td>
</tr>
<tr>
<td>Hardwood</td>
<td>2.6–7.0 HBS 1.6 10/100</td>
</tr>
<tr>
<td>Lead</td>
<td>5.0 HB (pure lead; alloyed lead typically can range from 5.0 HB to values in excess of 22.0 HB)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>15 HB</td>
</tr>
<tr>
<td>Copper</td>
<td>35 HB</td>
</tr>
<tr>
<td>Mild steel</td>
<td>120 HB</td>
</tr>
<tr>
<td>18–8 (304) stainless steel annealed</td>
<td>200 HB[4]</td>
</tr>
<tr>
<td>Glass</td>
<td>1550 HB</td>
</tr>
<tr>
<td>Hardened tool steel</td>
<td>1500–1900 HB</td>
</tr>
<tr>
<td>Rhenium diboride</td>
<td>4600 HB</td>
</tr>
</tbody>
</table>

Note: Standard test conditions unless otherwise stated
2. Rockwell hardness test

The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload.

$$HR = E - e$$

- $F_0 =$ preliminary minor load in kgf
- $F_1 =$ additional major load in kgf
- $F =$ total load in kgf
- $e =$ permanent increase in depth of penetration due to major load $F_1$ measured in units of 0.002 mm
- $E =$ a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter
- $HR =$ Rockwell hardness number
- $D =$ diameter of steel ball

Video: http://www.youtube.com/watch?v=G2JGNlIvNC4
3. Vickers hardness (diamond pyramid test)

» The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source.

\[
A = \frac{d^2}{2 \sin(136^\circ/2)},
\]

which can be approximated by evaluating the sine term to give

\[
A \approx \frac{d^2}{1.8544},
\]

where \( d \) is the average length of the diagonal left by the indenter in millimeters.

\[
HV = \frac{F}{A} \approx \frac{0.1891F}{d^2},
\]

where \( F \) is in newtons and \( d \) is in millimeters.

Video:
http://www.youtube.com/watch?v=7Z90OZ7C2jl
Example:

440HV30, or xxxHVyy/zz if duration of force differs from 10 s to 15 s, e.g. 440Hv30/20, where:

440 is the hardness number,
HV gives the hardness scale (Vickers),
30 indicates the load used in kgf.
20 indicates the loading time if it differs from 10 s to 15 s
Ductility

This is the property of the material that enables it to be drawn out or elongated to an appreciable extent before rupture occurs.

Measures of ductility

Percentage elongation or percentage reduction in area before rupture of a test specimen

Percentage elongation $> 15\% \rightarrow$ ductile material

Percentage elongation $< 5\% \rightarrow$ brittle material

Lead, copper, aluminium, mild steel are typical ductile materials.
Brittleness

> It is opposite to ductility. Brittle materials show little deformation before fracture and failure occur suddenly without any warning.

+ Percentage of elongation < 5% \(\rightarrow\) Brittle material

» Cast iron, glass, ceramics \(\rightarrow\) brittle materials
Malleability

> It is a special case of ductility where it can be rolled into thin sheets but it is not necessary to be so strong

In order of diminishing malleability:

> Lead
> Soft steel
> Wrought iron
> Copper
> Aluminium

Figure: Aluminum foil in flat shit form.
Resilience

> This is the property of the material that enables it to resist shock and impact by storing energy.

> The measure of resilience is the strain energy absorbed per unit volume.

Figure: The area under the linear portion of a stress-strain curve is the resilience of the material.
**Toughness**

- This is the property which allows a material to be twisted, bent or stretched under impact load or high stress before rupture.
- It may be considered to be the ability of the material to absorb energy in the plastic zone.
- The measure of toughness is the amount of energy absorbed after being stressed up to the point of fracture.
Creep

> When a member is subjected to a constant load over a long period of time it undergoes a slow permanent deformation and this is termed as a “creep”.

> This is dependent on temperature. Usually at elevated temperatures creep is high.

Figure: Creep on the underside of a cardboard box: a largely empty box was placed on a smaller box, and fuller boxes were placed on top of it. Due to the weight, the portions of the empty box not sitting on the lower box gradually crept downward.