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Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) —

Part 1: General algorithms utilizing mean value calculation

Applications ferroviaires — Calcul des performances de freinage (freinage d'arrêt, de ralentissement et d'immobilisation) —

Partie 1: Algorithmes généraux utilisant le calcul par la valeur moyenne

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 269, *Railway applications*.

A list of all parts in the ISO 20138 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes methodologies for calculation of braking performance, such as stopping distance, deceleration, power and energy for railway rolling stock. The calculations can be used at any stage of the assessment process (design, manufacture, testing, verification, investigation, etc.) of railway rolling stock.

The objective of this document is to enable the railway industry and operators to work with common calculation methods.

This document is published in two separate parts (ISO 20138-1 and ISO 20138-2), which will complement each other and can be used separately, depending on the requirements of the user.

The first part of the standard describes a common calculation method for railway applications applicable to all countries. It describes the general algorithms/formulae using mean value inputs to perform calculations of brake equipment and braking performance, in terms of stopping and slowing distances and safety for parking brake, for all types of trainsets and single vehicles. In addition, the algorithms provide a means of comparing the results of other braking performance calculation methods.

The second part of the standard details the step by step calculation methodology utilizing instantaneous values of brake force provided by each operational brake equipment type throughout the stopping/slowing time.

The two separate parts of the standard relate to each other but can be used separately, depending on the requirements of the user.

Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) —

Part 1: General algorithms utilizing mean value calculation

1 Scope

This document specifies methodologies for calculation of braking performance for railway rolling stock and is applicable to all countries.

This document describes the general algorithms/formulae using mean value inputs to perform calculations of brake equipment and braking performance in terms of stopping/slowing distances, stationary braking, power and energy for all types of rolling stock, either as single vehicles or train formations, with respect to the braking distance.

The calculations can be used at any stage of the assessment process (design, manufacture, testing, verification, investigation, etc.) of railway rolling stock. This document does not set out the specific acceptance criteria (pass/fail).

This document is not intended to be used as a design guide for selection of brake systems and does not specify performance requirements. This document does not provide a method to calculate the extension of stopping distances when the level of available adhesion is exceeded (wheel slide activity).

This document contains examples of the calculation of brake forces for different brake equipment types and calculation of stopping distance and stationary braking relevant to a single vehicle or a train.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20138-2[1)], *Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) — Part 2: General algorithms utilizing step by step calculation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
train
operational formation consisting of one or more units

1) Under preparation. Stage at the time of publication: ISO/DIS 20138-2:2018.

3.2
trainset
fixed formation unit that can operate as a train

3.3
unit
element of the train formation which can be composed of one or several vehicle(s)

3.4
vehicle
individual element of a unit

EXAMPLE Locomotive, coach, wagon, driving coach.

3.5
retention force
force, which is greater or equal than the sum of external forces and downhill force due to gravity

3.6
brake force
retarding force
forces generated by a brake equipment type or external forces

Note 1 to entry: The dynamic mass (sum of static and rotating masses) is braked by brake forces.

Note 2 to entry: Retarding forces are stopping or decelerating a vehicle or unit.

Note 3 to entry: In some cases (e.g. magnetic track brake), the brake force is equal to the retarding force. In other cases, a differentiation in brake force and retarding force is needed, e.g. calculation of required adhesion.

4 Symbols

For the purposes of this document, the general symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Definition	Unit
A_b	Contact area per brake block	m^2
A_c	Brake cylinder area	m^2
A_p	Contact area per brake pad	m^2
a	Defined level for the minimum output signal (typically 10 % or 5 %)	%
a_e	Equivalent deceleration	m/s^2
$a_{e,grad}$	Equivalent deceleration including the effect of gradient and inertia	m/s^2
$a_{e,grad\_simple}$	Equivalent deceleration neglecting inertia	m^2
$a_{e,z}$	Equivalent deceleration acting during speed range, z	m/s^2
α	Angle of slope	°
b	Defined level for the maximum output signal (typically 95 % or 90 %)	%
C_1	Characteristic coefficient of the train independent of speed	N
C_2	Characteristic coefficient of the train proportional to the speed	N/(m/s)
C_3	Characteristic coefficient of aerodynamic resistance due to pressure drag and skin friction drag	N/(m/s)^2
D	Wheel diameter	m
F	Force	N
F_{AMg}	Attraction force of one magnet	N

[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.

Table 1 *(continued)*

Symbol	Definition	Unit
$F_{AMg,st}$	Attraction force of one permanent magnet	N
F_B	Contribution of the friction brake	N
F_{Bd}	Blended retarding force	N
F_{BED}	Retarding force of electro-dynamic brake	N
$\bar{F}_{BED}$	Mean retarding force of electro-dynamic brake	N
$F_{BED,max}$	Maximum retarding force of electro-dynamic brake	N
F_{BFR}	Retarding force of fluid retarder	N
$\bar{F}_{BFR}$	Mean retarding force of fluid retarder	N
$F_{BFR,max}$	Maximum retarding force of fluid retarder	N
$\bar{F}_{B,n}$	Mean braking force of brake equipment type *n*	N
$F_{B,ind}$	Adhesion independent (not related to the wheel to rail contact) force, e.g. force of permanent magnetic track brake	N
$F_{B,ind,z}$	Adhesion independent (not related to the wheel to rail contact) retarding force per type of equipment	N
$F_{B,st}$	Total stationary brake force acting at the rail	N
$F_{B,ax,st}$	Stationary brake force acting on that wheelset	N
$F_{B,\tau,i}$	Adhesion dependent (related to the wheel to rail contact) retarding force generated by applied parking brake (i is an index used for sorting wheelsets)	N
$F_{B,\tau,req}$	Adhesion dependent (related to the wheel to rail contact) retarding force	N
$F_{B,\tau,req,rem}$	Remaining force of the mass to be held	N
F_b	Brake block force	N
$F_{b,st}$	Parking brake force acting on the tread of the wheel from a single parking brake unit	N
$F_{b,ax}$	Single brake block force	N
$F_{b,ax,st}$	Static single brake block force	N
$F_{b,tot}$	Total force acting on all disc faces or total brake block force	N
$F_{b,tot,st}$	Total static force acting on all disc faces or total static brake block force	N
$F_{Cr,H}$	Crank handle or hand wheel force	N
F_c	Internal cylinder force	N
F_{cl}	Clamping force	N
$F_{cl,n}$	Brake calliper clamping force	N
F_D	Downhill force due to gravity	N
$F_{d,ax}$	Proportion of downhill force to be resisted per wheelset with applied parking brakes	N
$\bar{F}_{ext}$	Mean external force	N
F_{ext}	External forces (e.g. wind force)	N
F_G	Output force of parking brake mechanism	N
F_g	Weight	N
$F_{g,ax}$	Static axle load	N
F_H	Retention force	N
$F_{Mg,st}$	Parking brake force of one permanent magnet	N
$F_{Mg,st,tot}$	Total parking brake force of all permanent magnets in a vehicle	N
[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.		

Table 1 *(continued)*

Symbol	Definition	Unit
F_N	Static axle load perpendicular to the rail per wheelset with applied parking brake	N
$F_{N,ax}$	Static axle load perpendicular to the rail per wheelset with applied parking brake for a specific wheelset	N
$F_{N,i}$	Static axle load perpendicular to the rail per wheelset with applied parking brake (*i* is an index used for sorting wheelsets)	N
$F_{N,rem}$	Remaining static axle load perpendicular to the rail	N
F_{PB}	Total parking brake force acting at the rail	N
$F_{PB,ax}$	Parking brake force per wheelset acting at the rail	N
F_{Perp}	Perpendicular force	N
$F_{Perp,ax}$	Perpendicular force at wheelset	N
F_p	Piston force	N
F_{pad}	Force acting on single disc surface	N
$F_{pad,n}$	Force acting on single disc surface	N
F_{pull}	Force on application point bogie	N
$F_{pull,st}$	Static force on application point bogie	N
F_{Ra}	Retarding force by train resistance	N
$\bar{F}_{Ra}$	Mean retarding force by train resistance	N
$F_{Ra,st}$	Stationary train resistance force	N
F_r	Instantaneous retarding force acting at the rail generated by the brake equipment	N
$\bar{F}_r$	Mean retarding force acting at the rail generated by the brake equipment	N
F_{rECB}	Instantaneous retarding force of linear eddy current brake	N
$\bar{F}_{rECB}$	Mean retarding force of linear eddy current brake	N
$F_{rECB,max}$	Maximum retarding force of linear eddy current brake	N
F_{rMg}	Retarding force of one magnet	N
$F_{rMg,tot}$	Total retarding force of all magnets in a vehicle	N
$\bar{F}_{r,n}$	Mean retarding force of brake equipment type *n*	N
F_{SP}	Parking brake spring force	N
$F_{S,C}$	Restoring force of brake unit or spring applied force	N
$F_{S,R}$	Restoring force, e.g. slack adjuster	N
F_{st}	Stationary brake force of the train	N
$F_{st,ax}$	Transmittable stationary brake force acting on that wheelset	N
$F_{st,n}$	Stationary brake force acting on the wheelset of each immobilization/holding/parking brake, *n*	N
$F_{s,rig}$	Restoring force	N
F_t	Tangential force	N
F_{wind}	Wind force on the train	N
g	Standard acceleration due to gravity	m/s^2
η_{Cbl}	Cable efficiency	—
η_c	Internal efficiency of brake unit	—
η_G	Gear efficiency	—
η_R	Overall efficiency of brake rigging	—

[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.

Table 1 *(continued)*

Symbol	Definition	Unit
$\eta_{R,st}$	Overall static efficiency of brake rigging	—
η_{rig}	Efficiency of brake rigging/calliper	—
$\eta_{rig,st}$	Static efficiency of calliper	—
I	Current	A
i	Gradient of the track (positive rising/negative falling)	—
i_{Cbl}	Cable mechanical ratio	—
i_c	Internal rigging ratio of brake unit	
i_G	Gear ratio	—
i_{max}	Maximum achievable gradient	—
$i_{max,roll}$	Maximum achievable gradient for rolling	—
$i_{max,slide}$	Maximum achievable gradient for sliding	—
i_{rig}	Rigging ratio	—
$i_{rig,ax,n}$	Lever ratio per brake beam	—
$i_{rig,C}$	Calliper lever ratio (parking brake)	—
$i_{rig,n}$	Calliper lever ratio	—
$i_{s,rig}$	Rigging ratio for restoring force	—
J	Inertia	kg·m^2
k_0, k_2	Coefficient (provided by the supplier)	—
k_1	Coefficient (provided by the supplier)	s/m
$k1_v$, $k2_v$	Factor describing an active or passive brake cylinder	—
l_a, l_b	Main brake lever length	m
$l_{a,n}$, $l_{b,n}$	Calliper lever length	m
l_e	Main brake lever length (parking brake)	m
l_c, l_d	Bogie lever length	m
M	Mass to be held of the vehicle/unit/train	kg
m_{dyn}	Dynamic mass	kg
m_{rot}	Equivalent rotating mass	kg
$m_{rot,ax}$	Equivalent rotating mass of the braked wheelset	
m_{st}	Static mass	kg
$m_{st,ax}$	Static mass per wheelset	kg
μ_{Mg}	Mean friction coefficient of magnet (pole shoe)	—
$\mu_{Mg,st}$	Static friction coefficient of permanent magnet (pole shoe)	—
μ_m	Mean friction coefficient of brake block/brake pad	—
μ_{st}	Static friction coefficient of brake block/brake pad	—
N	Number of brake equipment types	—
$n_{PB,ax}$	Number of wheelsets with applied parking brake	—
n_{Beam}	Number of brake beams	—
n_{BW}	Number of braked wheelsets	—
n_{disc}	Number of brake discs	—
n_{face}	Number of disc faces	—
n_{Mg}	Number of magnets in a vehicle	—
n_{SP}	Number of spring brake units	—
n_1, n_2	Value of power in speed range above v_{cha} normally obtained from supplier	—
[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.		

Table 1 *(continued)*

Symbol	Definition	Unit
$P_{max,n}$	Maximum power of brake equipment type *n*	W
p	Pressure	N/m^2
p_{ab}	Specific pressure per brake block	N/m^2
p_{ap}	Specific pressure per brake pad	N/m^2
p_c	Brake cylinder pressure	Pa [a]
r_m	Mean swept radius of the brake pad on the disc face	m
S_H	Retention safety	—
S_R	Safety against rolling	—
S_{st}	Safety ratio for stationary brake	—
$S_{\tau,slide}$	Safety against sliding	—
s	Stopping/slowing distance	m
$s_{B,n}$	Distance travelled while the brake equipment type *n* is applied	m
s_{grad}	Stopping/slowing distance on a gradient	m
s_0	Equivalent free running distance	m
t	Time	s
t_a	Initial delay (dead time)	s
$t_{a,n}$	Initial delay (dead time) for a specific brake equipment type *n*	s
t_{ab}	Build-up time	s
$t_{ab,n}$	Build-up time for a specific brake equipment type *n*	s
t_b	Overall response time ($t_a + t_{ab}$)	s
t_e	Equivalent response time	s
$t_{e,n}$	Equivalent response time for a specific brake equipment type *n*	s
$\overline{\tau}_{ax}$	Value of the mean adhesion required between wheel/rail for the braked wheelsets	—
$\overline{\tau}_{ax,i}$	Temporary value of the mean adhesion required between wheel/rail for the braked wheelset used during iteration step *i*	—
τ_a	Available adhesion	—
$\tau_{req,st,ax}$	Coefficient of adhesion required to resist the downhill and external forces by each braked wheelset	—
$\tau_{D,req,ax}$	Coefficient of adhesion required to resist the downhill force by each braked wheelset	—
τ_{max}	Maximum permitted or available static wheel/rail adhesion	—
$\tau_{req,ax}$	Coefficient of adhesion required by each braked wheelset	—
$\tau_{req,max,ax}$	Maximum required adhesion by each braked wheelset	—
v	Speed	m/s
v_{cha}	Characteristic speed (corresponding to maximum retarding force)	m/s
v_{fin}	Final speed	m/s
v_{max}	Maximum speed	m/s
v_0	Initial speed	m/s
$v_1 \ldots v_4$	Particular speeds	m/s
$v_{0,Mg}$	Activating speed of magnetic track brake	m/s
$v_{1,Mg}$	Deactivating speed of magnetic track brake	m/s

[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.

Table 1 *(continued)*

Symbol	Definition	Unit
W_B	Energy dissipated by the brake systems	J
$W_{B,n}$	Energy dissipated by brake equipment type *n*	J
W_{Ra}	Energy dissipated by the train resistance	J
W_{tot}	Total energy	J
Y	Percentage of output signal	—
z	Speed range step number	—
Z	Number of speed ranges	—
[a] bar or kPa is also allowed; 1 bar = 10^5 Pa.		

5 Stopping and slowing distances calculation

5.1 General

A summary of the methodology to establish the braking forces acting on the train is presented in Figure A.1.

The algorithms in this document use mean values and are applicable when the response time is less than 20 % of the time with the maximum braking force. For response times with a greater percentage (e.g. braking from low initial speeds) or where instantaneous values and algorithms are used or the finite time steps are preferred, ISO 20138-2 shall be used.

The mean value calculation is not intended to be used for an extreme value estimation or variation, e.g. minimum/maximum friction coefficient of friction couple. The input values for the calculation are used without tolerances.

The retarding forces expressed in this document are those acting parallel to the rail.

The brake system design parameters necessary to conduct the calculation shall be defined at the level of the wheelset, bogie, vehicle, unit or train. For the purpose of this document, the general term "vehicle" is used.

Calculations shall be performed for each brake equipment type (e.g. disc brakes, tread brakes, electro-dynamic brakes). All of the various types of brake equipment applied to the wheelset, bogie, vehicle, unit or train shall be identified and accounted for in the calculation.

When the brake equipment fitted to the train is used under different circumstances, e.g. load condition, speed range, brake demand, etc., each condition or state of the brake shall be considered together with the resultant effect on braking force.

This clause identifies how to calculate the braking force generated by each brake equipment type related to the retardation force at the rail. In general, calculations of stopping and slowing distances are based on the assumption of straight and level track.

Annex C provides examples for brake calculations of different vehicles and units.

The following subclauses consider the braking force generated by common brake equipment types. If other brake equipment types are used, e.g. new or novel types, then alternative methods of braking force calculation should be adopted.

Figure 1 gives a general overview of brake equipment types.

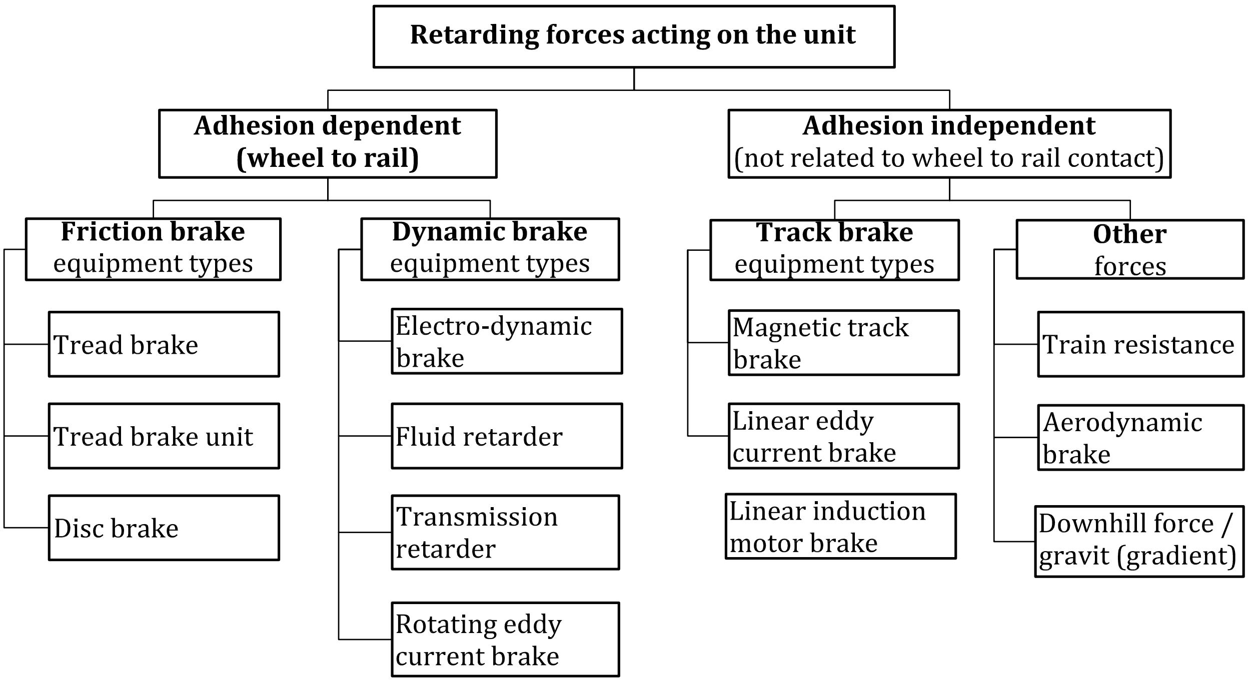

Figure 1 — General overview of retarding forces acting on the unit

5.2 Vehicle characteristics

5.2.1 Static mass, m_{st}

The static mass, m_{st}, of the vehicle and/or the static mass of a wheelset, $m_{st,ax}$, is assessed in stationary condition and shall be used to establish the braking force required or the adhesion requirements respectively for each applicable operating condition.

When there are different static masses per wheelset, $m_{st,ax}$, due to different vehicle arrangements, the braking force shall be calculated for each wheelset.

5.2.2 Equivalent rotating mass, m_{rot}

The equivalent rotating mass, m_{rot} is the linear conversion of the moment of inertia due to

— the rotation of the wheelsets, and

— the rotating parts coupled to the wheelsets during braking.

The equivalent rotating mass shall be determined using a theoretical approach or established as a result of tests. The wheel size applicable to the rotating mass shall be identified.

A value of equivalent rotating mass can be identified as a percentage of the static mass.

When there are different rotating masses, e.g. a mix of trailer and driven wheelsets, the rotating mass shall be determined for each type of wheelset.

For those wheelsets, if an inertia value, J, due to the rotating masses is known, the equivalent rotating mass using inertia is calculated in accordance with Formula (1):

$$m_{rot} = \frac{4 \cdot J}{D^2} \qquad (1)$$

where

m_{rot} is the equivalent rotating mass, expressed in kg;

J is the inertia, expressed in kg·m^2;

D is the wheel diameter, expressed in m.

NOTE The wheel diameter used for calculation of rotating masses is normally the maximum wheel diameter.

5.2.3 Dynamic mass, m_{dyn}

For the purpose of the calculation being conducted, the dynamic mass is the sum of the static mass and the equivalent rotating mass for the entity being considered, e.g. wheelset, bogie, vehicle, etc., in accordance with Formula (2):

$$m_{dyn} = m_{st} + m_{rot} \tag{2}$$

where

m_{dyn} is the dynamic mass, expressed in kg;

m_{st} is the static mass, expressed in kg;

m_{rot} is the equivalent rotating mass, expressed in kg.

5.2.4 Wheel diameter

The wheel diameter, D, is the diameter at the rolling contact point between the wheel and the rail.

When the vehicle is equipped with different sizes of wheels (by design not due to wear), each size of wheel shall be determined.

NOTE 1 The wheel diameter used for calculation of stopping and slowing distances is normally the maximum wheel diameter.

NOTE 2 The wheel diameter used to determine the required adhesion, $\tau_{req,ax}$, is normally the minimum wheel diameter.

5.3 Adhesion wheel/rail dependent brake equipment type characteristics

5.3.1 Basic brake cylinder

This subclause describes the calculation of piston force as an output force of the brake cylinder.

The first step is the calculation of the internal cylinder force, F_c [see Formula (3)].

Efficiency, ratios, friction resistances and moduli of resilience, etc. are not considered in the formula of calculation of the cylinder force.

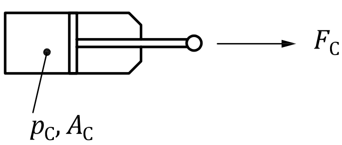

Figure 2 — Basic principle of a pressure applied cylinder