INSTRUCTION MANUAL

FOR

MAGNETIC SUSCEPTIBILITY BRIDGE

KAPPABRIDGE KLY - 2

5. METHODOLOGY OF MEASUREMENT

6. FINAL INFORMATION

Geofyzika n. p. Brno
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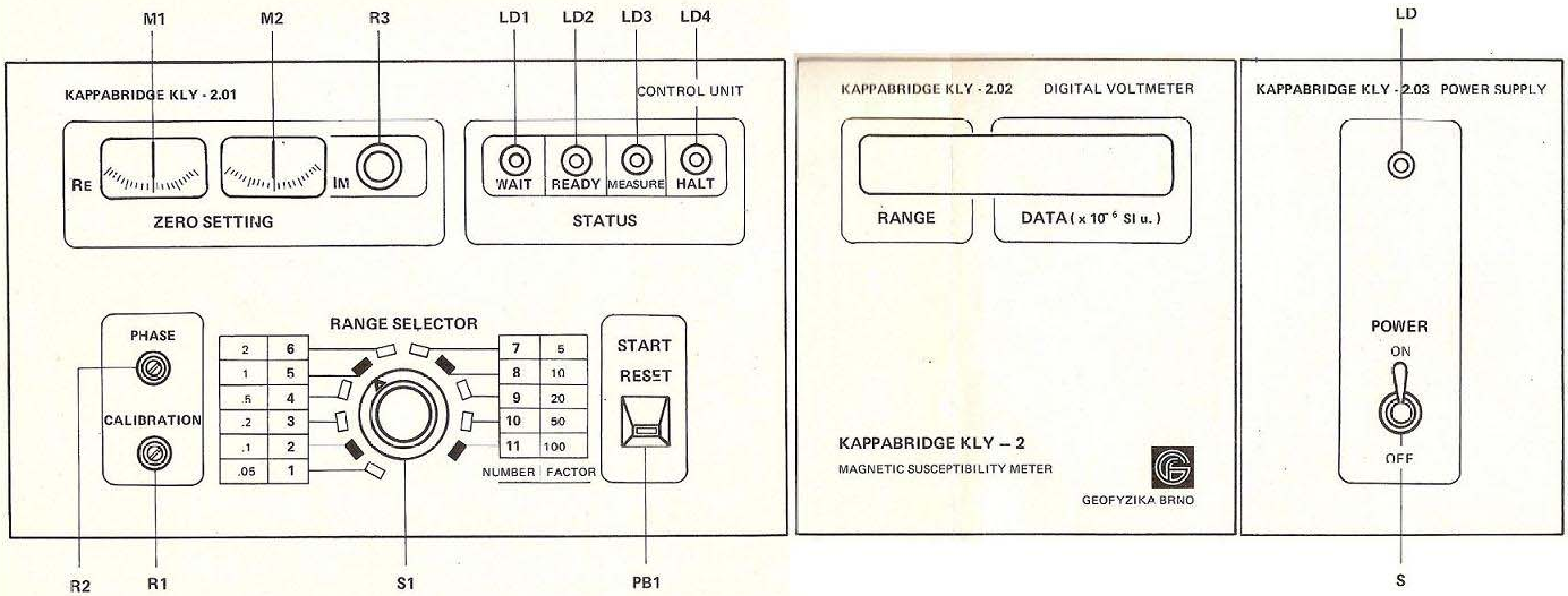


Fig. 7 Front panel of the measuring unit KLY - 2.0

INFLUENCE OF THE SPECIMEN HOLDER

When specimens with very low **SB** are measured we have to consider the influence of the holder. The holder is made of diamagnetic material (perspex, polyamide). The holder as a whole shows a certain negative **TSB** ϑ_D.

An immediate result of the measurement is the directional **TSB** of the specimen with the holder. The directional **TSB** of the specimen itself is then calculated from the equation

$$\vartheta_D = \vartheta'_D - \vartheta_H$$

5 METHODOLOGY OF MEASUREMENT

GENERAL INFORMATION

5.1.1 Installation of the bridge, arrangemet of the working place

The bridge must be installed in a magnetically undisturbed environment with a constant temperature. There must be no sources of **AC** or pulse magnetic fields, e.g. large transformers, eletric motors, contactors, etc., in the laboratory and its vicinity. The room must be closed and the heating (or air conditioning) such that the changes of temperature are minimmal and as slow as possible.

The arrangement of the working place is illustrated in Fig. 9. The measuring unit is placed on the table top desk. The pick-up unit is located on a special stand close to the left-hand edge of the table or rather shifted somewhat forward. The top surface of the pick-up unit should be with the surface of the top desk. With his left hand the operator inserts and pulls out the specimen from the pick-up unit and controls the measuring unit with his right hand. The distance between the operator and the pick-up unit should be as large as possible.

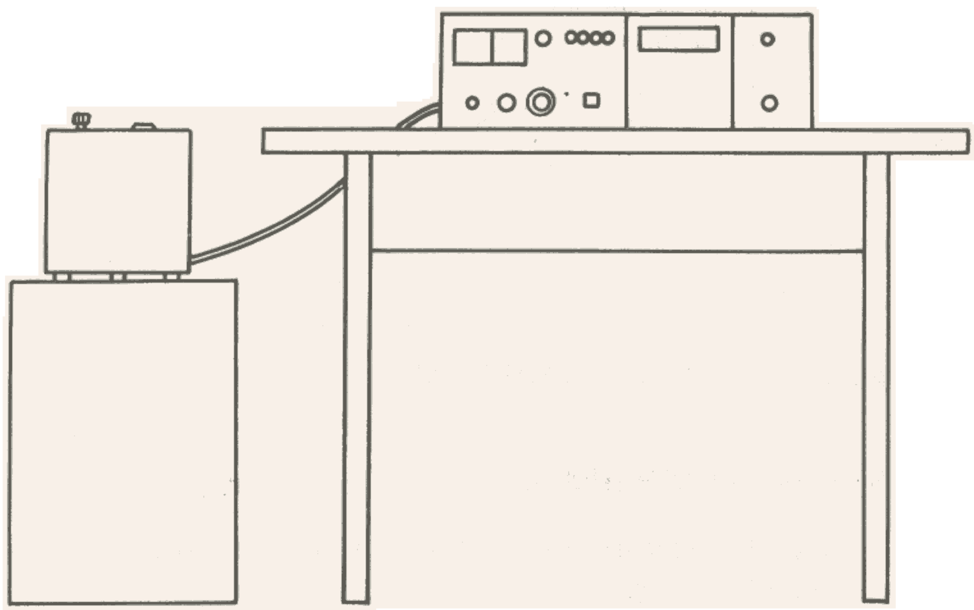


Fig. 9. **Kappabridge KLY-2** working place arangement

The working top desk, the stand of the pick-up unit and the chair of the operator must not be made of metal to avoid disturbing the pick-up unit. The operator should work without wrist-watch, rings, etc.

The pick-up unit and the measuring unit are connected by a cable, in the measuring unit, the cable should be connected to the lower twelve-pin connector designated **AA** in Fig. 8.

It is recommended to connect the terminal **ST1** to an operational earthing. However, it does not have protective function.

5.1.2 Shapes of specimen, holders

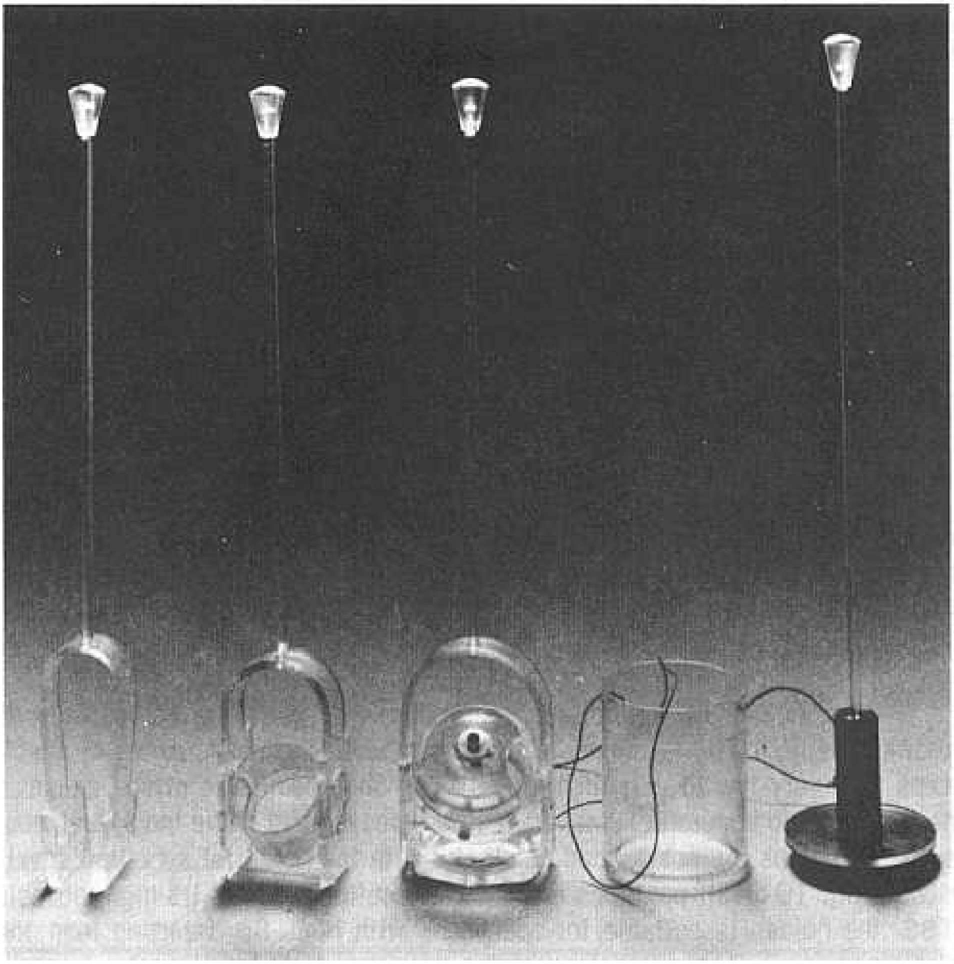
In the KLY-2.1 pick-up unit cubic specimens with an edge of 20 mm (8 cm^3), cylindrical specimens ϕ 25.4 x 22 mm (11.15 cm^3) or crushed specimens in the 40 cm^3 measuring vessel can be measured.

The holder of cubic specimens is illustrated in Fig. 10 a. The holder of cylindrical specimens with a cylindrical capsule is in Fig. 10 b. This holder consists of two parts; the specimen is inserted in a capsule that is put in the holder. The holder of cylindrical specimens with a spherical capsule is similar, see Fig. 10 c.

The holder of cylindrical specimens with a cylindrical capsule as shown in Fig. 10 b, is universal. It can be used for measurement of specimens with very low to very high **SB**´s. The shape and size of the specimen need not be too accurate. However, it is a disadvantage if the individual measuring positions are not defined precisely. With the holder of spherical specimens (Fig. 10 c) all positions are precisely defined; due to its high intrinsic **TBS** the holder is suitable for specimens with high **SB** (starting from the 3rd range, say). The dimensions of the specimen must be accurate, in particular the length.

The KLY-2.2 pick-up unit is designated for measurement of cubic specimens with an edge of 38 mm (54.87 cm^3), cylindrical specimens ϕ 46 x 40 mm (66.48 cm^3) and specimens in the measuring vessel with the capacity of 240 cm^3.

The holders, the measuring vessel and the calibration standard are quite similar to those of the KLY-2.1 . As an addition, a holder of spherical specimens 50 mm in diam. (65.45 cm^3) has been designed.



a b c d e

Fig. 10. Accessories of the pick-up unit KLY-2
a) cubic specimen holder
b) cylindrical specimen holder with cylindrical capsule
c) cylindrical specimen holder with spherical capsule
d) measuring vessel
e) calibration standard

According to the customer's specification, holders of cubic and cylindrical specimens of slightly different dimensions can be delivered. This mainly concerns the KLY-2.2 unit.

5.1.3 Calibration standards

A standard of susceptibility is delivered with each pick-up unit.

The standard for the KLY-2.1 pick-up unit is in Fig. 10e; the standard for the KLY-2.2 differs in dimensions only. In the bottom cylindrical part of the standard, there is a small ferromagnetic particle.

On each standard there are written

a) the registration number
b) the nominal volume V_0
c) the number of the range for which the standard is designed
d) the nominal reading of the display **DATA**.

The reading **DATA** is determined by the reference bridge, previously calibrated with the primary standard. A coil of precisely defined dimensions that is inserted into the measuring coil of the bridge and is loaded with a suitable two-pole of mainly inductive character, is used as the primary standard.

5.1.4 Measuring ranges

The measuring ranges are given in the following table:

Range No	Range factor 10^{-6} (SI)	Full range 10^{-6} (SI)
1	0.05	100
2	0.1	200
3	0.2	400
4	0.5	1 000
5	1	2 000
6	2	4 000
7	5	10 000
8	10	20 000
9	20	40 000
10	50	100 000
11	100	200 000

The ranges are switched over with the **S1 RANGE SELECTOR** (Fig. 7). Each position of the selector is designated with the respective range factor. The sequential number of the range is also indicated by the display **RANGE**.

Data measured by the digital voltmeter are indicated by the display **DATA** with 3 1/2 digits, i.e. the value shown is within the range 0 to ± 1 999.

The directional **TSB** of the specimen with the holder is calculated according to equation

$$\vartheta'_D = K\ X \quad 0^{-6}$$

K is the range factor, **X** the reading of the display **DATA**.

5.2 INSTRUCTIONS FOR MEASUREMENT

In this section we are referring to Fig. 7.

5.2. Switching on and off

It is necessary to make sure that the voltage on the type label is the same as that of the mains.

The bridge is switched on by setting the switch **S** (POWER) to the position. The operating state is indicated by the green **LED** diode **LD** on the panel. The bridge then transfers to the status **WAIT** (red **LD1**), or to the status **READY** (green **LD2**). Also the displays **RANGE** and **DATA** light up.

The bridge is switched off by setting the switch **S** (POWER) to the position **OFF**.

5.2.2 Zeroing

The zeroing is manual and automatic. In manual zeroing the real component of unbalance (corresponding to detuning in the inductive component, i.e. in **SB**) as well as the imaginary component (corresponding to detuning in the resistive component). Automatic zeroing concerns the real component only and within the lowest 6 ranges it also includes automatic drift compensation. The zeroing is performed with the specimen out of the bridge.

Manual zeroing must be performed after switching the bridge on and repeated during the operation if, in the chosen measuring range, any of the indicators **M1** R_E and **M2** I_M shows a deflection exceeding 1/2 of the scale.

Manual zeroing is performed in the status **WAIT** (red **LD1** on or **READY** (green **LD2** on). If the bridge is in the status **HALT** (red LD4), it is brought to **WAIT/READY** by pressing the button **PB1 START/RESET**. If the bridge is in the status **MEASURE** (yellow **LD3** on), it enters the status **HALT** automatically. Then **PB1** is pressed.

The procedure is as follows:

1. Check if needles of panel meters R_E and I_M are within the scale range. If so, go to 3.
2. Turn **RANGE SELECTOR** clockwise until needles of R_E and I_M are within the scale range.
3. Set zero on R_E with the button on the pick-up unit, set zero on I_M with the potentiometer I_M.
4. If the chosen range (i.e. the range in which we intend to measure) is identical with the range set, the zeroing is accomplished.
5. Turn the **RANGE SELECTOR** counter-clockwise and improve the accuracy of zeroing until the chosen range is reached.
   The zeroing is accomplished.

Note: As we sometimes do not know in advance in which range we shall measure, it may be useful to increase the accuracy of zeroing until the first range is reached.

If the bridge is manually zeroed or if at least the needle deflections on R_E, I_M are within the tolerance, automatic zeroing is going on in the statuses **WAIT**, **READY** and **HALT**. In the status **WAIT**, its course can be observed on the display **DATA**.

Let us presume that after the operation with the bridge (zeroing, range switching, removal of the specimen at a wrong moment) the reading of the display **DATA** is not zero and the bridge is in the status **WAIT**. The voltmeter measures repeatedly the residual unbalance that drops to zero in the lowest 6 ranges with one overshoot, in the other ranges aperiodically. After some time the display reading drops to zero. With a delay of several seconds the bridge converts to the status **READY** and is ready for measurement.

It may occur that in the status **READY** the balance is disturbed due to an outside effect. In such a case the bridge passes to the status **WAIT**. However, within a short time it reverts to the status **READY.**

5.2.3 Measurement of **TSB** of specimen with holder

The measurement of directional **TBS** is a basis for measuring the mean **SB** and the anisotropy of **SB** (see 5.3 and 5.4). Of special importance is the selection of the measuring range (5.2.4).

The procedure of measurement:

1. Set the bridge to the status **WAIT** or **READY** according to 5.2.2.
2. By turning **RANGE SELECTOR** set the chosen (corrected) measuring range. If necessary, perform zeroing manually.
3. If the bridge is in the status **WAIT**, wait until it converts to the status **READY** by automatic zeroing.
4. Press the button **START/RESET**, the bridge enters the status **MEASURE**. Insert the specimen into the pick-up coil as quickly as possible and remove hands from the pick-up unit.
5. Approx. 4 s after pressing **START/RESET** an acoustic signai sounds. Take the specimen out quickly and remove hands.
6. After another 3 s the bridge enters the status **HALT** . If blinking 1999 appears in the display **DATA**, the bridge is overloaded and the measurement must be repeated in a higher range.
   If the display does not flash, judge, according to the criteria in 5.2.4, whether the appropriate measuring range has been selected. If so, record the reading. Otherwise change the range.

If the second or any subsequent measurement of the directional **TSB** of the same specimen is concerned, and the bridge is not overloaded, record the reading.

7. Press the button **START/RESET**. The bridge enters the status **WAIT** or directly the status **READY**.
8. If the range need not be changed, continue from item 3. In the opposite case find the corrected range according to 5.2.4 and continue from 2.

Note In the status **WAIT** the button **START/RESET** is disabled so that the measurement cannot be started. Similarly, the push-button is disabled in the status **MEASURE**.

The directional **TSB** of a specimen with holder is calculated according to eq. (24).

5.2.4 Measuring range selection

This is a slightly complicated matter as there is a great number of ranges, and each switching of the range selector means a loss of 10 - 20 s before the bridge reaches the steady state again.

As mentioned in 4.4 and 4.5, several directional **TSB**´s are measured on one specimen: to determine the mean **SB** usually 3 **TSB**´s, to determine anisotropy 15 **TSB**´s. All these directional **TSB**´s must be measured in one range. We try to find the lowest range in which the bridge will not be overloaded by any of the directional **TSB**´s measured.

In order to be able to select the measuring range according to certain rules, we shall assume that the values of the second and of any subsequent directional **TSB** are 25 % higher at the most than the first **TSB** measured, according to which the range is being selected. This assumption can be changed with respect to the degree of anisotropy of the particular material studied.

When measuring the mean **SB** we shall limit ourselves to the decadic ranges only, i.e. ranges 2, 5, 8, 11 with corresponding factors 0.1, 1, 10, 100 x 10^{-6}.

By way of trial the decadic range where the value **X** of the first **TSB** measured is within 160 - 1600. We can end in the first decadic range without fulfilling this condition; we shall then measure in this range. Similarly, we can end in the highest range without fulfilling the condition. If there is no overload when the first directional **TSB** is measured, we can try to make the whole measurement because it is likely that the overload will not occur during measurements of further **TSB**´s.

When measuring the anisotropy of **SB** we make use of all ranges in order not to lose the resolving power.

For the directional **TSB** we are seeking a range where **X** is roughly within 640 - 1600 and 800 - 1600; for the ranges 4, 7, 10, and for the remaining ranges, respectively. Limitations in the lowest and in the highest range are analogous to the previous case.

To seek the range just by trial and error would be too tedious in this case. Therefore, we shall use a different way. First we try to find the decadic range where **X** is within 32 - 1999. (If we do not reach the value 32 even in the lowest decadic range, we shall measure in the first range). We shall then correct the range according to the table:

Reading **X**	Range Correction
1600 - 1999	+1
800 - 1599	0
320 - 799	-1
160 - 319	-2

Reading **X**	Range Correction
80 - 159	-3
32 - 79	-4

Example: In the range 8 we have found that $X^{\cdot} = 220$. Therefore, we shall measure 2 ranges lower, i.e. in the range 6.

5.2.5 Measurement of the **TSB** of the holder

The **TSB** of the holder ϑ_H is measured in the same way as the directional **TSB** of the specimen with the holder described in 5.2.3. It is a certain simplification that the measurements are always made in the lowest range. There are **N** measurements (usually N = 5) made for the given holder. The arithmetic mean is taken for the result,

$$\vartheta_H = 0.05 \frac{1}{N} \sum_{i=1}^{N} X_i \tag{25}$$

where X_i is the reading of the display **DATA** for the **i**-th measurement.

5.2.6 Calibration

It is essential to calibrate the bridge every day before begining the work. Besides, the instrument must be calibrated always when the pick-up unit is changed.

For calibration we use the respective standard. We read the range sequential number and the nominal reading X_N on the display **DATA**, see section 5.1.3. We shall then zero the bridge, set the range **R** and measure the directional **TSB** of the standard. If the indicated value **X** is higher (lower) than the nominal value X_N, we turn the potentiometer **CALIBRATION** counter-clockwise (clockwise). We repeat the procedure several times until **X** and X_N coincide.

The instrument should be calibrated at a temperature of approx C.

5.2.7 Setting the phase conditions

This is performed in longer time intervals and always when the pick-up unit is changed.

In range **5** the bridge is accurately zeroed. With the knob I_M set about 1/2 of the f.s.d. of the meter I_M. In connection with this the reading of the meter R_E may change. The meter R_E is reset to zero by the potentiometer **PHASE**. The procedure is repeated several times.

Check of the stabi ty of zero

Errors in measurements of specimens with low **SB**, and thus also the sensitivity, depend on the stability of zero. The stability is influenced by the noise of the instrument, the irregular thermal drift of coils, disturbing magnetic fields, mechanical vibrations, etc.

The stability of zero can be checked. We zero the bridge in the lowest range and measure a "zero specimen", i.e. we do not insert any specimen in the measuring coil. The instability of zero is usually due to inconvenient working conditions. On the other hand, the instability may indicate a defect of the instrument.

5.3 MEASUREMENT OF THE ANISOTROPY OF SUSCEPTIBILITY

To determine the anisotropy of **SB** means finding the tensor of **SB**, a system of three principal **SB**´s and a system of the respective principal directions.

For the measurement of the anisotropy of **SB** we choose the rotatable pattern of 15 directions described in (1). In this system the respective directional **TSB**´s are measured.

In measuring in the lowest ranges it is recommended to measure each directional **TSB** twice and to calculate the average that is taken for the result. If the difference of the two values for a certain **TSB** is too great, the measurement should be repeated.

Now we shall show how the rotatable pattern mentioned is applied to a cubic and to a cylindrical specimen. (As the measurement of a spherical specimen is too special, it will not be described here).

Note that the system of directions is defined in the so-called specimen coordinate system, the axes x_1, x_2 and x_3 of which are associated with the characteristic directions in the geometrical shape of the specimen.

5.3.1 Cubic specimen

The axes of the coordinate system are identical with the edges of the specimen. The specimen is marked with a simple, a double, and a triple arrow as illustrated in Fig. 11.

The specimen is inserted in the holder so that it successively assumes all the 15 positions shown in Fig. 12.

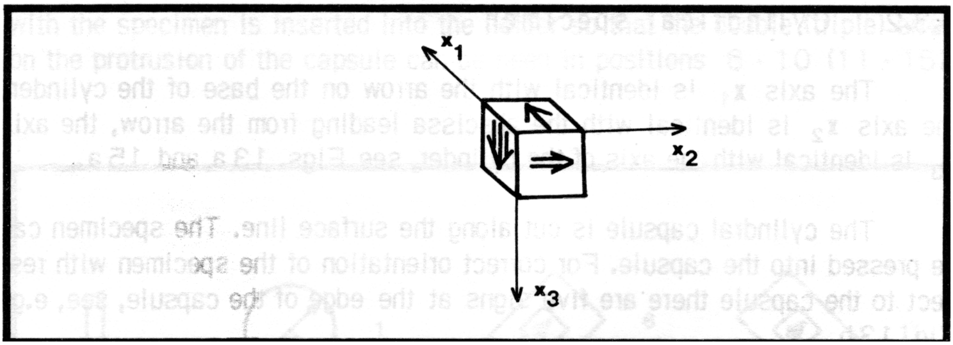


Fig. Cubic specimen marking for anisotropy measurements

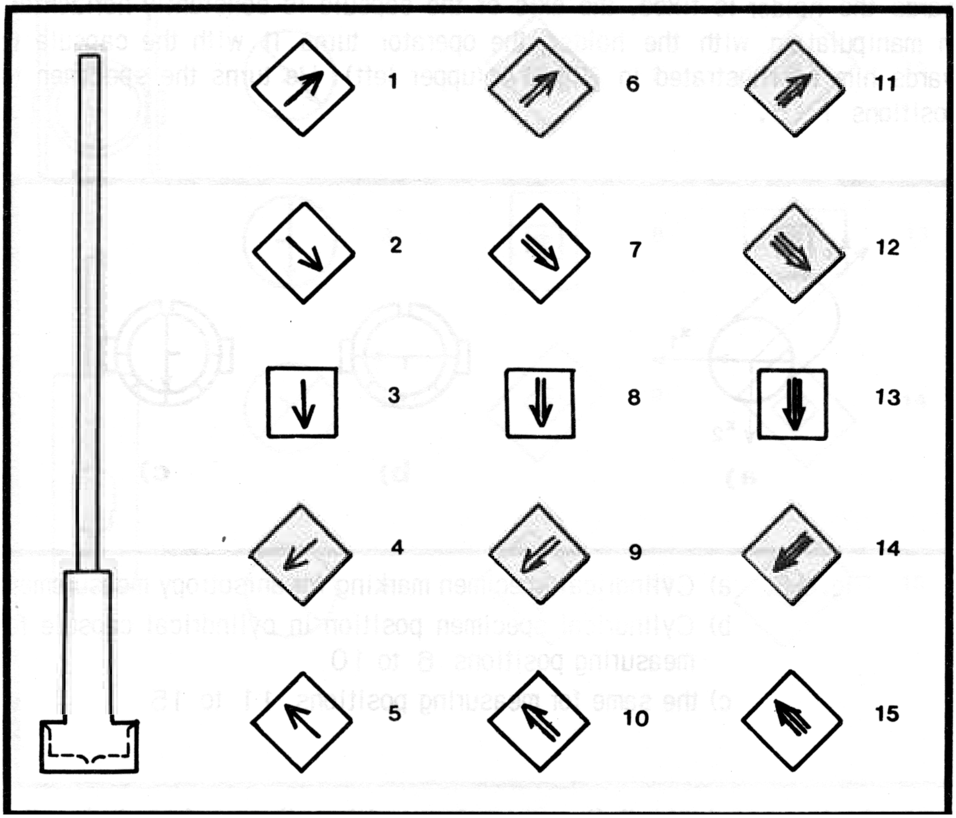


Fig. 2. Implemenation of the rotatable pattern of 5 measuring directions for a cubic specimen

5.3.2 Cylindrical specimen

The axis x_1 is identical with the arrow on the base of the cylinder, the axis x_2 is identical with the abscissa leading from the arrow, the axis x_3 is identical with the axis of the cylinder, see Figs. 13 a and 15 a.

The cylindral capsule is cut along the surface line. The specimen can be pressed into the capsule. For correct orientation of the specimen with respect to the capsule there are five signs at the edge of the capsule, see, e.g., Fig. 13 b.

In the first five measuring positions, the position of the capsule towards the holder is fixed, the axis of the capsule is constantly horizontal. In manipulating with the holder, the operator turns it with the capsule to wards him as illustrated in Fig. 14 (upper left). He turns the specimen to positions 1 - 5.

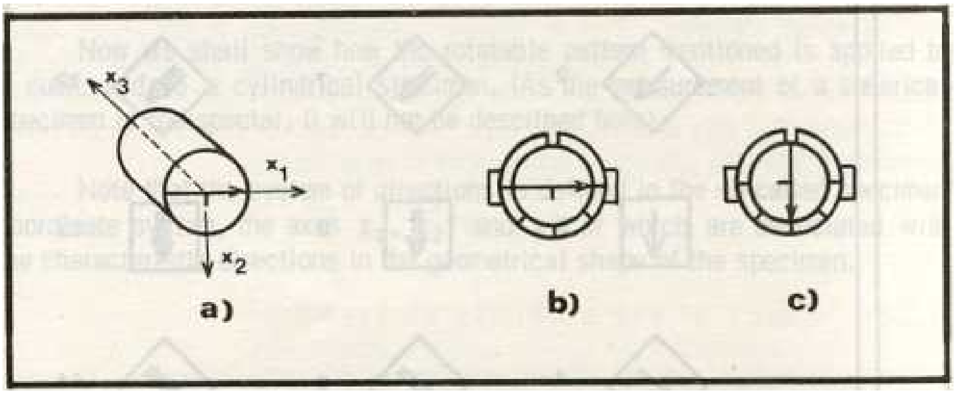


Fig. 13. a) Cylindrical specimen marking for anisotropy measurement
b) Cylindrical specimen position in cylindrical capsule for measuring positions 6 to 10
c) the same for measuring positions 11 to 15

In the second (third) five measuring positions the specimen is in a fixed position towards the capsule as in Fig. 13 b (13 c). The operator turns the holder towards him as illustrated in Fig. 14 (below left). The capsule with the specimen is inserted into the holder so that the double (triple) arrow on the protrusion of the capsule can be seen in positions 6 - 10 (11 - 15).

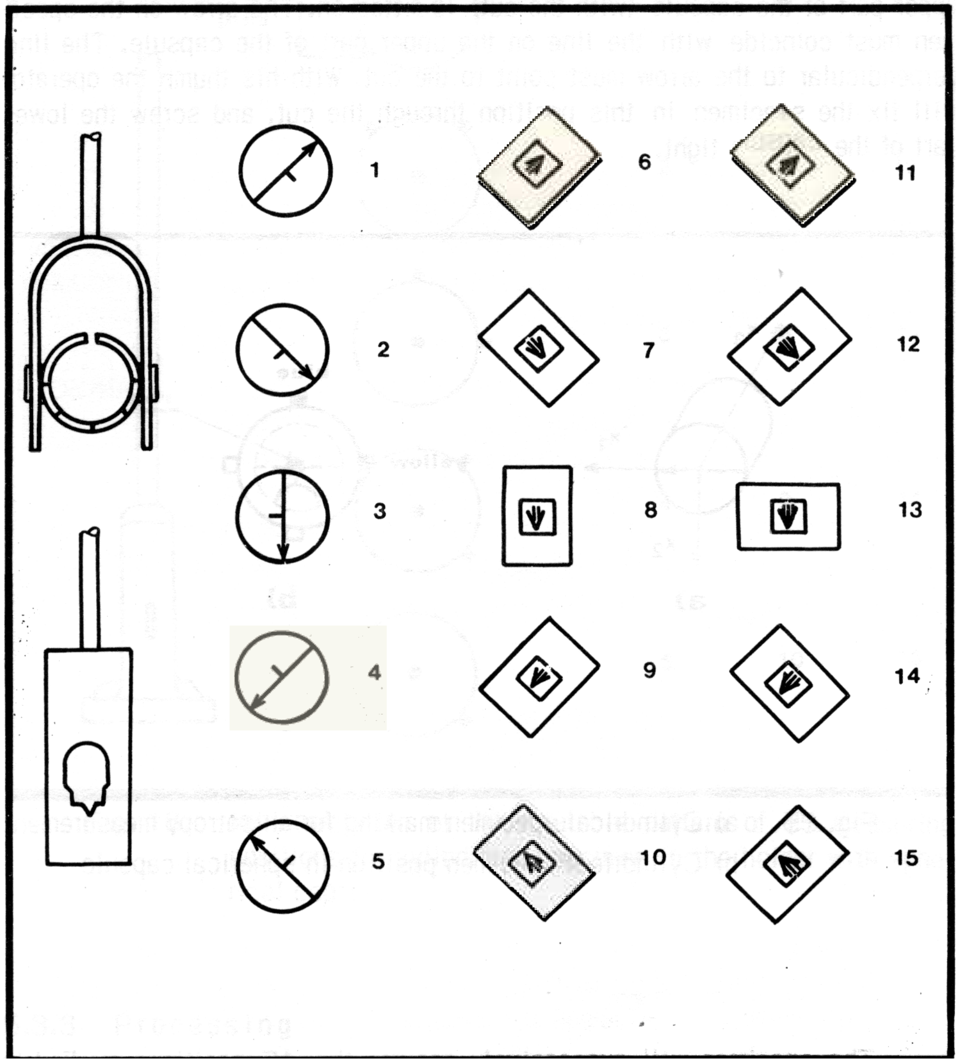


Fig. 14. Implementation of the rotatable pattern of 15 measuring positions for cylindrical specimen in the holder with cylindrical capsule

The measurement with the holder with the spherical capsule is slightly simpler. Before the measurement the specimen is fixed in the capsule. The capsule is screwed apart, a rubber inset is inserted into the lower part (without the cut) and the specimen is placed on it with the marked side up. The upper part of the capsule (with the cut) is fitted on. The arrow on the specimen must coincide with the line on the upper part of the capsule. The line perpendicular to the arrow must point to the cut. With his thumb the operator will fix the specimen in this position through the cut, and screw the lower part of the capsule tight.

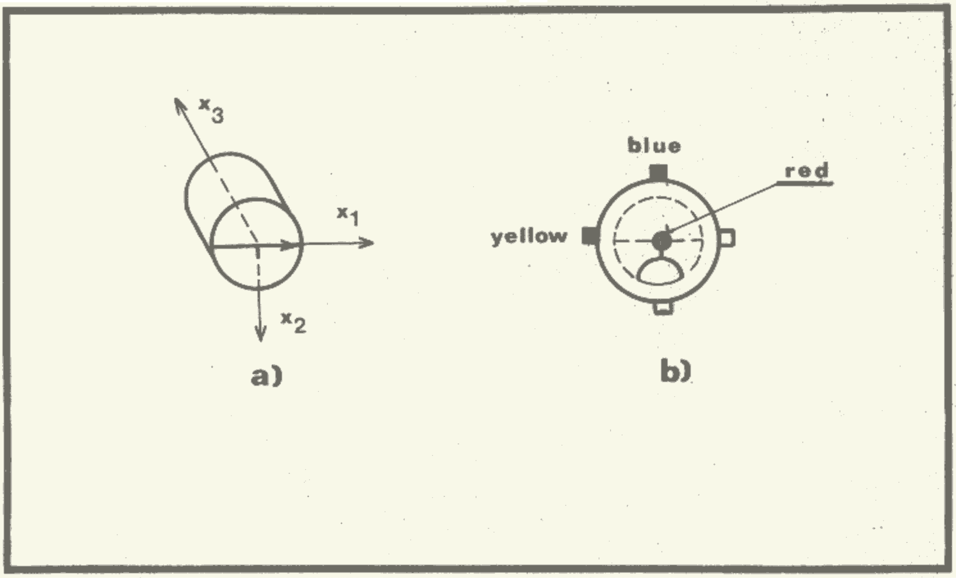


Fig. 5. a) Cylindrical specimen marking for anisotropy measurement
b) Cylindrical specimen position in spherical capsule

The specimen will successively assume the 15 positions marked in Fig. 16. There are 6 pins protruding from the spherical capsule for fixing the specimen in these positions. 3 of these pins (red, yellow and blue) serve for identification.

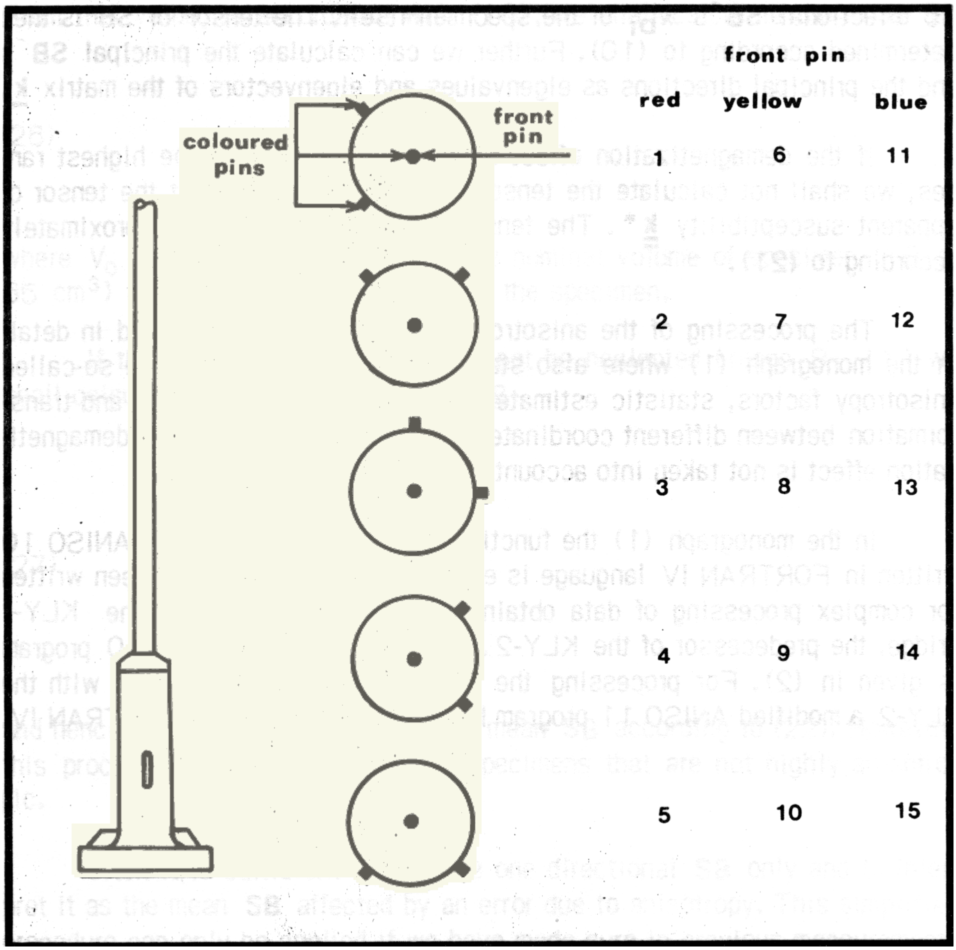


Fig. 16. Implementation of the rotatable pattern of 15 measuring positions for cylindrical specimen in the holder with spherical capsule

5.3.3 Processing

The result of the measurement are 15 directional **TSB**´s of the specimen with the holder ϑ_{Di}. After subtracting the **TSB** of the holder ϑ_H according to (23) and the correction for volume according to (19) we obtain

15 directional SB´s $\varkappa_{Di}$ of the specimen itself. The tensor of **SB** is then determined according to (10). Further we can calculate the principal **SB**´s and the principal directions as eigenvalues and eigenvectors of the matrix $\underline{\mathbf{k}}$.

If the demagnetization effect cannot be neglected in the highest ranges, we shall not calculate the tensor of susceptibility $\underline{\underline{k}}$, but the tensor of apparent susceptibility $\underline{\underline{k}}^*$. The tensor $\underline{\underline{k}}$ can be determined approximately according to (21).

The processing of the anisotropy measurements is described in detail in the monograph (1) where also static tests, calculation of the so-called anisotropy factors, statistic estimates of precision of the results and transformation between different coordinate systems are included. The demagnetization effect is not taken into account.

In the monograph (1) the function of the computer program ANISO 10 written in FORTRAN IV language is explained. This program has been written for complex processing of data obtained by measurements with the KLY-1 bridge, the predecessor of the KLY-2. The listing of the ANISO 10 program is given in (2). For processing the data obtained by measuring with the KLY-2 a modified ANISO 11 program has been written also in FORTRAN IV.

5.4 MEASUREMENT OF THE MEAN SUSCEPTIBILITY

5.4.1 Cubic, cy ndrical and spherical specimens

First we shall measure three directional **TSB**´s of the specimen with the holder ϑ'_{D1}, ϑ'_{D2}, ϑ'_{D3} in three mutually perpendicular directions. (With cubic and cylindrical specimens the directions may be those corresponding to positions 3, 8, 13).

We shall now calculate the arithmetic mean ϑ' and subtract the **TSB** of the holder from it. In this way we shall obtain the approximate mean **TSB**ϑ.

From this value, in accordance with (19), we shall calculate the mean **SB**

$$\varkappa = \frac{V_0}{V} \vartheta$$

where V_0 , as already mentioned, is the nominal volume of specimen 0 or 65 cm^3) and **V** is the actual volume of the specimen.

If the demagnetization effect cannot be neglected (range 9 - 11 we shall calculate the approximate mean **SB**

(27) $$\varkappa^* = \frac{V_0}{V} \vartheta$$

and hence the approximate value of the mean **SB** according to (22). However, this procedure can only be used for specimens that are not highly anisotropic.

Often it is sufficient to measure one directional **SB** only and to interpret it as the mean **SB** affected by an error due to anisotropy. This simplified procedure can only be applied if we have made sure in previous measurements that the error due to the anisotropy of the rock considered is not too big.

Fragment specimens

We shall crush the specimen into fragments with which we fill the measuring vessel. If there is no other possibility, only one fragment of a sufficient size can be used.

The mean **SB** must be so low that neither the demagnetization effect of the fragments nor their mutual interaction need be considered. On this assumption, the mean **SB** of the adapted specimen in the measuring vessel is equal to the mean **SB** of the original specimen; however the adapted specimen is less anisotropic.

If this is not true, an error appears in the measurement that we can easily correct.

Now we shall measure the directional **SB** of the specimen in the measuring vessel several times, and after each measurement we shall shake the vessel and thus change the positions of the fragments inside. We shall calculate the arithmetic mean of the obtained values $\vartheta'_{D1}, \vartheta'_{D2}, \ldots, \vartheta'_{Dn}$. We shall then subtract the **TSB** of the specimen ϑ . The mean **SB** is then calculated according to the equation

$$\varkappa = \frac{V_0 \, s_0}{m} \, \vartheta$$

where V_0 is the nominal volume, s_0 the bulk density of the specimen, m the mass of the specimen.

If the anisotropy of the rock is low and/or the number of the fragments in the measuring vessel is large enough, a single measurement will suffice.

A NOTE ON THE SENSITIVITY OF THE BRIDGE

We shall define the sensitivity of the bridge in the following way. Let us measure the directional **TSB** of the specimen repeatedly. Let the value of the measured quantity be very small so that the measurement can be made in the lowest measuring range. By the sensitivity of the bridge we shall understand the standard error of the measured directional **TSB**.

If the volume of the measured specimen is equal to the nominal volume V_0, the sensitivity is obviously equal to the standard error of the directional **SB** of the specimen.

The sensitivity of the bridge has been verified by measuring a perspex (methylacrylate) specimen. The voltmeter has been expanded by another, less significant digit; quantization noise corresponding to the usual number of digits has been included. A series of twenty measurements, repeated several times, has enabled us to estimate the sensitivities of the KLY-2.1 and KLY-2.2 units at 3×10^{-8} and 2×10^{-8}, respectively. In the specifications we have intentionally given a "safer" value, i.e. 4×10^{-8}.

If the anisotropy of **SB** of the specimen with a low **TSB** is measured, the standard error of the directional **TSB** may be a little higher than the sensitivity. Here additional disturbing effects associated with turning the specimen in the holder appear.

6 FINAL INFORMATION

6. MAINTENANCE

In routine operation the instrument does not require special maintenance. The surface of the bridge should be dusted, as well as the inside of the tubular inset of the pick-up coil. The holders should be cleaned.

6.2 SERVICING

It is recommended to call our servicing engineers to make all repairs and resetting of the instrument. Please contact the manufacturer:

Geofyzika n.p. Brno, Ječná 29a, 612 46 Brno, Czechoslovakia

6.3 STORAGE AND TRANSPORTATION

The wrapped instrument can be stored and transported at a temperature from $-25°C$ to $+55°C$ and relative humidity up to 80%. In both cases the instrument should be stored in suitable premises, free of dust and chemical evaporations.

6.4 WARRANTY

All information concerning the period of guaranty is given in the certificate of warranty.

6.5 COMPLETE DELIVERY

Measuring unit **KLY-2.0**

Standard pick-up unit **KLY-2.1**

Unit for large specimens **KLY-2.2** (optional)

Accessories

Mains cord
Interconnecting cable
Holders of specimens (according to the packing list)
Standards (according to the packing list)
Spare fuses
Instruction manual including diagrams
Packing list
Certificate of warranty