SAP FLOW METER T4.2

Instruction Manual

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CONTENT:

1. GENERAL FEATURES

Sap flow meter T4.2 is twelve-channel battery operated system for the field measurement of sap flow in small stems or branches of size between 6 and 20 millimeters.

The system is designed as a closed unit containing all necessary parts for the measurement and logging the sap flow values in terms of [kg/hr].

The sap flow gauges can be easy and fast installed. At least 20 cm long part of stem or branch is needed for sensor placement, including the protection against the rain and irradiation.

Gauges are soft and flexible, thus allowing the stem or shoot to grow freely about five to ten millimeters in diameter during the sap flow measurement without reinstallation.

2. MEASURING PRINCIPLE

The measuring method is based on the heat balance of artificially heated part of stem. The heat balance of xylem through which the sap flow passes can be described by the equation:

$$P = Q \cdot dT \cdot c_w + dT \cdot z \qquad (1)$$

where P is the heat input power [W], Q is the sap flow rate [kg/sec], dT is the temperature difference in the measuring point, c_w is the specific heat of water [J/kg, deg] and "z" is the coefficient of heat losses from the measuring point [W/deg]. The amount of water in terms of mass or volume passing through the measuring point in the stem is calculated from the actual power and temperature rise of water passing through the heated space.

The T4.1 system uses the modification with constant dT and variable power. The electronic feedback units control the heating power in gauges in order to maintenance the temperature difference in certain level.

The calculation of sap-flow values derives from the equation [1], from which:

$$Q = \frac{P}{c_W \cdot dT} - \frac{z}{c_W} \qquad \text{[kg/s]} \qquad (2)$$

The second term of this formula represents the heat losses from the sensor. Its magnitude can be easily estimated from the data recorded under condition of actual flow approximating zero, i.e., during the zero evaporating demands as during the rain or at night before sunrise.

The measurement is continual and gives absolute values in terms of mass flow that need not to be calibrated.

3. SYSTEM DESCRIPTION

The measuring system includes the watertight box containing the electronics, sap flow gauges and connecting cables.

The electronics includes heating units and datalogger which are working mostly independently. Nevertheless, the datalogger supervises the heating in order to avoid the overheating of the plants in case of feedback failure of a unit. In such a case when the datalogger find the unit heating with maximal power more that ten minutes it switches it off for next fifty minutes. Than, the unit is reset and it runs again. The status of emergency switching off is indicated with red light by appropriate unit. On the other hand, the datalogger reads automatically the position of switches of individual channels and changes their ON/OFF setting accordingly.

The electronic circuits are designed for maximal power efficiency in order to save the energy and consequently current consumption from the batteries. Since the power consumption is directly proportional to the sap flow rate that is proportional to solar radiation, using the solar technique for power supplying is very effective.

The sap flow gauges have the same parameters (heating resistance, output voltage) independently on the size so they can be exchanged or connected to any channel without the setup change. The measurement of heating power is also made the way independent on the cable parameters (length, size).

The sensor protection against the ambient factors in made with a special Mylar weather shields. They reflect the sunshine, reduce the influence of natural temperature gradients and protect gauges against the rain and wind.

4. SPECIFICATION

Number of channels	Twelve for small stems or shoots
Range of sensor diameters	two sizes: 8-12mm and 12-20mm
Heating technique	External soft and flexible heater
Output variable	Sap flow in [kg/hr]
Temperature sensors	Special thermocouple
Temperature difference	4 Deg.C, controlled
Resistance of heaters	100 Ohm
Heating current	Maximum 0.125 Amp per channel
Heating power	Maximum 1.6 W per channel, variable according to sap flow magnitude
Datalogger resolution	16 bit
Accuracy	0.1 % of the full scale
Memory capacity	220 000 values
Internal memory	512 kByte
Measuring interval	10 sec to 2 min
Storage interval	10 sec to 24 hrs

Energy supply	12 – 15 Volts d.c.
Current consumption	Max 2.2 Amp. Generally, the power consumption is proportional to the sap flow rate and the number of channels in use. Daily average of 0.2 to 0.5 Amp is estimated.
Working temperature	-10 to 40 Deg.C
Weight	8 kg box, 12 kg cables, 2kg sensors and accessories
Box size	43 x 33 x 20 cm

5. OPERATION

The device can work when hanged or laying everywhere. The sturdy design of T4.2 fits to harsh terrain conditions. Sap flow gauges are connected with cables to the device box with 7-pin Amphenol C16-1 connectors. Power supply (battery) is connected similar way with 4-pin connector. Computer for datalogger setting and data downloading connects to common 9-pin D-sub connector placed on the front panel behind the door. The device box and all connectors are waterproof (protection class IP 65).

5.1. Sensor installation

Correct installation of measuring points on trees is an ultimate pre-requisite of getting correct results. Interactions between sensors and living tissues belong generally to important points of this type of measurement.

5.1.1. Sensor location on trees

Fundamental criteria for location of measuring points at tree stems or shoots are the stem/branch shape and the height above ground. The highest temperature gradient, which may interfere with the measurement, occurs close to the ground surface. That's why measuring points should be placed as high as possible above ground, but anyway below the first living whorl or foliated part of the shoot (if results should represent the whole tree or shoot). Rather straight parts of stems/shoots about 20 cm long should be selected to install the gauges. Stem or branch should be roughly cylindrical, with no irregularities such as larger knots, mechanical or biotic injuries, etc., simply anything that could influence the exact contact between the surface and the heater. It is also necessary to consider enough space above and bellow the gauge where the Mylar shield should be fastened. **See Appendix T**.

5.1.2. Sensor set up

Installation of the gauges is very simple but it must be done gently and very carefully. One should realize that the sensor should not affect the plant but on the other hand it should survive even a storm.

- Remove the rest of bark, needles, small knots and similar stuff which would avoid the perfect heat contact between the heater and the bark surface.
- Open both tin housings of the gauge and remove the thermocouple assembly from them.
- Fasten the plastic clip of the thermocouples at the suitable place of the stem (shoot). Fasten the cable below the measuring point with the plastic tape. Attach thermocouples at the stem surface and press the sharp tips inside the stem with your fingers **until the strait part of the needle touches the bark**. Pay attention not to damage the sensor by violent rotating of the needle in the cube when pressing the tip crooked way. Use a knife tip (carefully - watch your fingers!) to prepare a slot for the needle spike in hardwood.
- Apply the upper housing of the heater to the stem with already installed thermocouples and close it. **No direct contact of** (yellow) **heating elements with thermocouples should be assured.** The correct position of the heater along the stem is indicated by the foam insulation touching the upper edge of the cube. Then put the lower foam insulation on the stem below the cube with its upper edge just touching the lower end of the cube (see picture in appendix).
- After carefully checking the correct position of the gauge, install the weather shield. Cut its both tails according to stem diameter (the original size fits to lowest – 6 mm one) and place the shield over he sensor. Note that the lateral folds should overlap each other.
- Fix both ends with a plastic tape (at least the upper one in watertight manner). The fold of the shield must be pointed down to allow condensed water to run off.
- Connect the sensor with extension cable to the equipment.

5.2. Datalogger setting

Please read the Mini32 software manual first for the proper datalogger handling. Anyway, even the first setting of non-customized datalogger is quite easy – just fill in the channel description with respect to measured stem/branch identification. It is good idea to initialize the datalogger (if the internal clock time should be changed) or just erase the datalogger memory in order to erase old data which do not regard to current job.

Since there is direct link between switching the hardware channels and appropriate channels of datalogger, don't worry about the channel ON/OFF setting. **The datalogger channel status automatically follows the hardware setting.**

5.3. Power supplying

5.3.1. Power supply voltage requirements

As the system supposes supplying from 12 Volt lead acid battery, the supply voltage higher that 12.1 Volts is necessary to start operation. Such a voltage indicates discharged battery and its next withdrawing would shorten its lifetime. When already running, the system is automatically switched off when the battery voltage drops bellow 11 Volts for the same reason. In the same time the datalogger stops logging data.

When the system is supplied with a power adapter, the minimal output voltage of 12.5 Volts is recommended.

5.3.2. Auxiliary batteries

6 x AAA alkaline batteries placed just bellow the front panel keep the datalogger running when the system is out of main power. When they are missing, the datalogger keeps data and work properly anyway; just an external power brake during the measuring process could stop logging data until midnight. The batteries also maintain the energy for communication with datalogger (setting, download data) in case of missing main power supply.

5.4. Switching on

The main switch is located on the bottom of front panel inside the device box. After switching on, the green lights of main units of both six channel sections will be on indicating the powering.

Than, the channels can be switched on with appropriated switches. Since this moment the switched units start to heat until the temperature difference in each sensor reaches four degrees centigrade. The time of stabilizing depends basically on the sap flow magnitude and it could take a minute. During this time, the red LED indicating the channel status can be on indicating "full power" heating. Note that if the datalogger main operation switch is ON (by software), the channels start log data immediately when at least one channel is ON, too.

5.5. Operation indicators

5.5.1. Main unit in a six channel section – green light

It indicates the power supplying of all six units. It must light up after MAINS is on. Otherwise the fuse (common for both sections) is broken or the supply voltage is lower that 12.1 Volts while switching on or 11.0 Volts during operation.

5.5.2. Power units – red light

It is normally off. It lights when:

- the steady state has been not reached yet - the unit runs in full power. Few seconds or a minute only.

- the unit has been switched off by datalogger that has found it running in full power longer than ten minutes. Perhaps due to broken cable, wrongly installed sensor or due to another failure. It will be switched on again within 50 minutes. If the problem continues, the cycle is repeated.
- the sap flow in unexpectedly high – more that 0.3 kg/hr. The available heating power is not able to maintain the demanded temperature difference. When lasting longer than ten minutes, the sensor heating will be switched off similarly as described above
- the unit is broken

5.5.3. Indicators visible from outside (closed doors).

- Flashing red LED – it collects information of all (covered by doors) units. Something gets wrong. Check measured values with computer and switch off the bad sensor. Than check its installation and the cable and sensor. Exchange them if they are damaged.
- Green LED – system runs O.K.
- Yellow LED – indicates broken fuse
- Red LED – indicates wrong polarity of main power supply (battery)

5.5.4. Display

The information on the display depends on how the datalogger was switched off last time. Basically it should show time (usually), "OFF" (when the datalogger status is off) or simply nothing (when it was switched off during the running measurement - in such a case the time appears as late as at midnight). However, the display information is always refreshed by first communication between the datalogger and computer.

- Time **HH:MM** – normal operation (shows the time of last measurement)
- **batt** – low main power supply voltage
- **- - - -** (four dashes) – datalogger in operation (measuring, communicating with computer)
- **OFF** – datalogger operation is stopped by software setting
- **nothing** - main (HW) switch is off or there is no power available (both main power and aux. batteries are (or has been) down. In some cases after the switching the system on the display information appears as late as after next regular measurement or after communication with PC.

5.5.5. Auxiliary batteries status green LED

The LED must light up when pushing the check button. Replace batteries when it does not.

5.6. Data handling

All the datalogger manipulations and data handling need connected PC compatible computer running Windows© 95 or later operating system or Windows© NT, 2000, XP.

The program for datalogger controlling, Mini32, is placed on two disks 3.5 inch which is a part of the delivery.

The individual options of the program assure the datalogger setting, data downloading, file processing and firmware uploading.

The options in main menu give three basic types of operations:

- the datalogger setting
- on-line data handling
- operating with data files, export to another software.

Please refer to Mini32 software manual for more information.

5.6.1. Sap flow values calculation

The sap flow values in terms of [kg/hr] are calculated from the measured electrical values according to the channel setting automatically during the conversion from downloaded *.hex file to *.dcv file format suitable for next operation. However, the manual baseline subtracting (supported by software) is necessary for getting final values.

5.6.2. Baseline subtraction

The Mini32 software is ready for graphic subtracting of the "baseline" that represents the heat loses from the measuring point (see Eq. 2). This option appears only when a sap flow system is recognized by software.

The time course of sap-flow values from a chosen channel is displayed on the screen. The cursor will appear together with it, which allows you to create a line connecting the points on the curve that shows the situation at 3 a.m. - zero line. In this way it is possible to prepare channels assigned for sap flow measurement and then do subtraction in all channels at the same time. The filename with character "&" at the end is offered and this is the file with the correct sap flow values expressed in [kg/hour].

When creating the zero-line, it is necessary to consider the possibility of the night flow during warm summer nights, sudden changes of heat losses and of fictive flow consequently during the changes sapwood water volume, etc. The specialist's experience on the field of plant water relations is very valuable here, though a possible mistake from the point of flow quantity is not crucial.

5.7. Switching off

Before the finishing of the measurement it is always recommendable to download the data and check them carefully. Do not forget to complete the biometric information which might be necessary for the data interpretation. Check again the shoot – sensor association to avoid future doubts. Than

- Switch of the hardware channels (recommended but not necessary)

- Switch off the main switch. Disconnect extension cables and remove sensors.

5.8. Sensor dismounting

Sequence of dismounting operations:

- Remove the weather shields carefully – they can be use again for similar or large diameters
- Open both tin housings of the heater and remove them from the stem
- Carefully remove tops of both needles from the plant tissue (by knife-tip inserted between the plant and needle) and dismount the sensor completely
- Dry out gauges if necessary and store them into original housing

5.9. Maintenance

Principally, the sap flow rate measuring equipment does not need any special maintenance **except of replacement of aux. batteries.** It should be done each year for sure although under normal condition (no long time switched on without main power) they should last for years. Check the battery status by pressing the check button. Replace batteries when the green LED does not light up.

6. WARRANTY

The producer warrants right function of the sap flow rate measuring device for three years after it is accepted by a customer. All the faults will be removed free of charge during this time, at the measuring device itself as well as at sensors. The producer is not responsible for the faults originated by careless manipulation, incorrect operations, wrong applications or theft.

APPENDIX A:

Useful images concerning the proper installation.

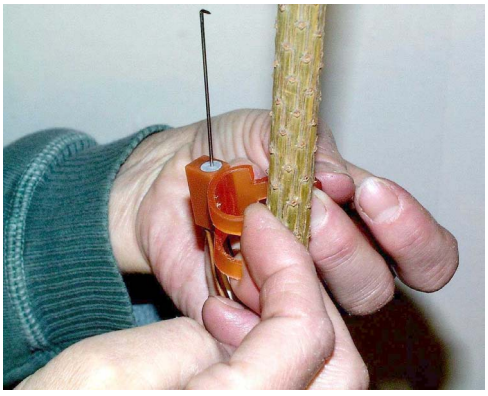
Choose the right place on the branch or stem, remove dry rests of bark from the surface (just by hand), tape the cable and place the temperature sensor assembly.

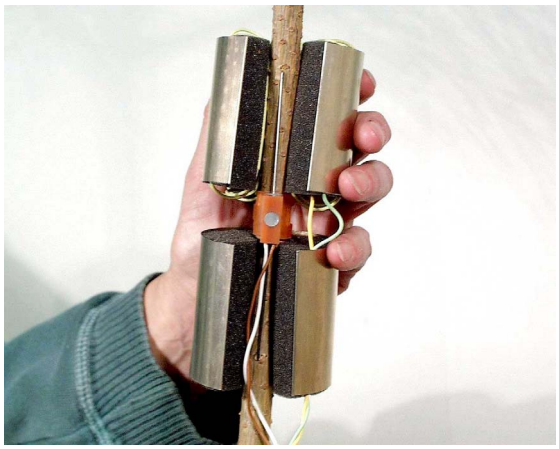
Front view:

Needles as straight as possible.

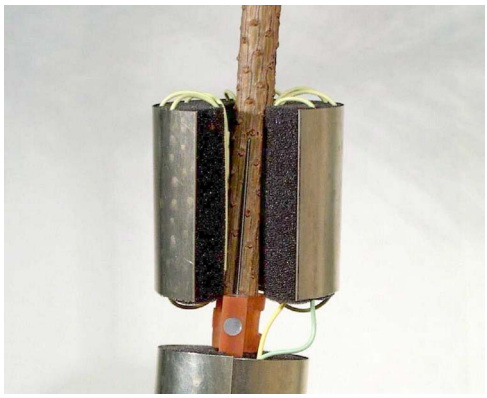
Important! Needle tips should be completely pushed in the stem. The end of straight part should be in full contact with the bark.

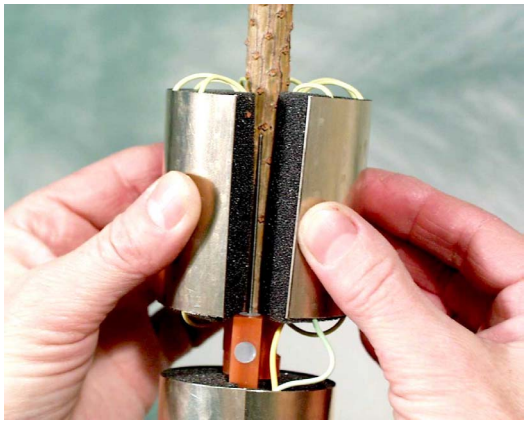
Flexible clip holds the temperature sensor in exact position and prevents strangulation.





Put the heater and compensating part over the thermosensor assembly. Watch the needle to avoid the direct contact with heating elements (yellow pipe)





and

close carefully.

As the result, the heater should look like this:

Mylar weather shield is designed to protect the sap flow gauge against the sunshine and the rain as well. Careful placement is necessary in order to prevent getting wet. Be sure the overlap is always pointing downwards. Tape the upper end against the stem flow and lower for fixing. Cut both ends to fit to thicker stems.