EMS 62

SAP FLOW SYSTEM

for small stems or branches

Instruction Manual

(January 2010)

CONTENT:

1. GENERAL FEATURES 2

2. MEASURING PRINCIPLE 3

3. SYSTEM DESCRIPTION 4

4. SPECIFICATION 5

5. OPERATION 5

5.1. Sensor installation 5
5.1.1. Sensor location on stems 5
5.1.2. Sensor set up 6

5.2. Module set-up 7
5.2.1. Error messages 7

5.3. Sap flow calculation 7

5.4. Data handling – EMS dataloggers 8
5.4.1. Sap flow values calculation 8
5.4.2. Baseline subtraction 8

5.5. Switching off 9

5.6. Sensor dismounting 10

5.7. Maintenance 10

6. TOOLS 10

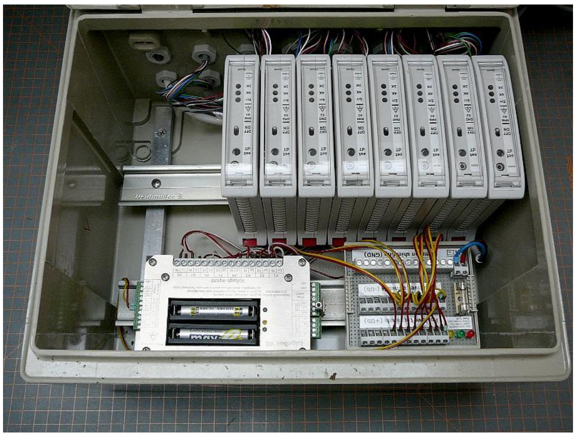
7. WARRANTY 11

LITERATURE: 11

1. GENERAL FEATURES

Sap flow module EMS 62 is one-channel battery operated system for the field measurement of sap flow in small stems or branches (further just stems) with the diameter between 6 and 20 mm. The module is intended for cooperation with SF 60 sensors.

The module is designed as an independent unit designed for to DIN-rail mounting. The unit contains all electronics necessary for the sap flow measurement based on SHB (stem heat balance) method with external heating and variable power.

The module is supplied with 11 to 16 V D.C. The power consumption is proportional to the sap flow rate and it ranges between ca 20 and 150 mA. Output signal voltage is proportional to the heating power and it can be directly measured or registered by any common datalogger.

The installation of measuring point is fast and easy. Just a special drill is necessary for drilling holes for needles in xyloid stems.

A weather shield is necessary in order to cover the measuring point against direct solar radiation, wind and rain. Approximately 20 cm of free stem is demanded for proper sensor installation.

2. MEASURING PRINCIPLE

The measuring principle is based on the stem heat balance method (SHB) with external heating and internal temperature sensing (Lindroth et al. 1995, Čermák et al. 2004). The senor consists of two similar cylindrical parts. Each part wraps the stem with insulation foam. One part contains linear heating elements which are gently pressed to the stem by soft foam. A needle thermocouple is inserted to the stem in radial direction at the level of upper edge of heating elements (in direction of water movement). Second cylinder has no heaters and it just covers the reference needle thermocouple located with respect to the thermal symmetry. The water passing along the sensor is warmed and the temperature increase is measured with thermocouples as the water leaves the heated space. The feedback loop of EMS 62 module maintains the temperature difference at preset level 2 K or 4 K. Then, the input power is directly proportional to the amount of water passing the sensor in terms of kg/hr. However, there is still a part of energy that is dissipated by heat losses from the sensor.

The heat balance of the heated part of the stem is described by the general equation:

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

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 sensor [W/deg]. The amount of water in terms of mass or volume passing through the sensor is calculated from the actual power and temperature rise of water passing through the heated space.

The calculation of sap flow rate is derived from the equation [1], from which:

$$Q = \frac{P}{c_W * d * dT} - \frac{z}{c_W} \quad \text{[kg/s, cm]} \qquad (2)$$

First part of the equation represents energy used for heating-up the water. The second part 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 a rain or at night before sunrise. The supporting software Mini32 includes an option for easy graphic baseline subtracting.

In order to easy handle the signal output at both selected temperature differences (2 and 4 K), the output of EMS 62 module is generated in terms of power per temperature difference, P/dT [mW/K, hr]. **This way, the output does not depend on the preset dT value!**

3. SYSTEM DESCRIPTION

The measuring system includes the EMS 62 controlling module, sap flow sensor SF 60, radiation shield, connecting cables and a datalogger.

The module electronics includes the power unit, the temperature and heating power measuring circuits, the controlling system and the output D/A convertor.

Electronic circuits are designed for maximal power efficiency in order to save batteries. The power consumption is directly proportional to heating power.

EMS 62 controlling module is not protected against weather. It is designed for DIN-rail mounting into an enclosure together with a datalogger and power terminals.

There are two dimensions of sap flow sensors according to the stem thickness (6 to 12 mm and 10 to 20 mm). Both sensor sizes have the same resistance of heaters (100 ohms) and the measuring method is independent on the cable resistance. Therefore, the output signal does not depend on the size of the sensor and the cable size and length.

4. SPECIFICATION

Stem diameter range	6 to 20 mm covered by two sensor types: 6 to 12 mm and 10 to 20 mm
Heating technique	external heating of stem
Output variable	heating power per dT [mW/K]
Sensor heater resistance	100 ohm (± 0.5 ohm)
Temperature sensing element	Thermocouple T-type in 0.6 mm needles
Output signal conversion factor	-25 + 0.25*U [mW/K, mV] > P/dT -0.0215 + 0.000125*U [kg/hr/ mV] > Q
Necessary stem length for sensor installation (incl. radiation shield)	20 cm
Preset dT values	2 or 4 K
Heating power	variable, up to 2 W
Power supply	12 – 15 Volts D.C.
Current consumption	Max 0.15 Amp. according to the sap flow magnitude
Working temperature	-10 to 40 Deg.C
Weight	ca 0.1 kg module, 0.1 kg sensor
Module box size	160 x 80 x 60 mm

5. OPERATION

The sensor is designed for easy installation on a stem when its diameter is in specified range (6 to 12 mm for small sensor and 10 to 20 mm for large sensor). It needs about 20 cm of length on the stem however, a small knob can find place between both sensor parts where the cube of thermocouple assembly is located. The sensor is connected with a 20 m long special cable to an enclosure with EMS62 modules, datalogger and other accessories. There are also extension cables offered which allow to increasing the sensor distance from the box up to 50 meters.

5.1. Sensor installation

Correct installation of measuring points on trees is an ultimate pre-requisite of getting correct results. Interaction between sensors and plants belongs generally to important points of this type of measurement.

5.1.1. Sensor location on stems

Fundamental criteria for location of measuring points are the necessary stem length for sensor installation and the height above the ground. The highest temperature gradient which may interfere with the measurement occurs close to ground surface. Therefore, the measuring points should be placed as high as possible. Measuring on seedlings or agricultural plants where the sensor has to be installed just close to the soil could be affected by a serious error especially in the morning when the temperature gradient close to the ground is huge.

Also in tree crowns, a shaded space for sensor installation is recommended in order to reduce a potential error caused by solar irradiation.

5.1.2. Sensor set up

Choose the right part of stem for sensor installation. At least 20 cm stem length is necessary.

Clean the stem from a rest of rough bark, needles etc.

Fix the thermocouples assembly on the stem

Insert needles into the stem. Drill holes for needles in xyloid stems if necessary.

Set the upper sensor part with heater on the stem. Watch the proper position:

- the foam should be in touch with the cube of thermosensor holder
- the sensor tin cover should keep its cylindrical shape and it should be placed symmetrically around the stem
- the thermocouple needle cup should be pressed by both foam edges below the cover clip

Put the lower (unheated) part on the stem similar way. Make sure it position is symmetrical to the upper sensor part with respect to central cube.

Cut both ends of the radiation shield with respect to stem diameter roughly according to the following table:

Stem diameter [mm]	Cut length [mm]	
	Upper end	Lower end
6	0	2
8	1	3
10	3	5
12	5	7
14	7	9
16	9	10
18	11	12
20	13	14

Install the radiation shield. Fix the upper end with a PVC tape in a watertight manner.

Form the shield in the "diamond" like shape

Fix lower end over the cable by PVC tape. Do not tight it too much – let a gap between the stem and the cable for drainage of condensed water.

Connect cables.

See also an installation instruction manual.

5.2. Module set-up

The module starts operation after switching on the switch on the front panel bellow the transparent lid. The necessary battery voltage for start is 12.1 V in order to avoid on/off oscillations under flat battery status. The module is automatically switched off when the powering voltage drops below 10.5 Volts.

Besides of the main switch, the front panel also contains

- 2.5 jack connector for service system setting and checking
- press-button for switching between 2 K and 4 K temperature difference setting
- LED indicators indicating preset dT and an error status.

5.2.1. Error messages

All kind of errors are indicated by just one red LED placed on the front panel. It indicates following troubles by flashing in one second intervals

- disconnected sensor cable
- broken thermocouples
- broken heater

With flashing in five second intervals the red LED indicates that the senor heating has been stopped due to ten minutes long heating with full power. It occurs when

- the sap flow rate is too high so the sensor power can't maintain the preset temperature difference or
- in case of a sensor malfunction that could lead to stem damage by overheating.

In such a case, the module will try to continue in operation after two hours again.

5.3. Sap flow calculation.

Sap flow values are in terms of [kg/h, cm] are calculated from the output signal [mV] according to the formula

$$Q = -0.0215 + 0.000215 * U_{sig} \qquad (3)$$

The formula is derived from equation (2) with respect to module output signal conversion factor [mV] > [mW/K].

Note that this way calculated sap flow values include the power loss from the measuring point that has to be (graphically) subtracted!

Derivation details:

$$Q[kg/h] = \frac{P[W]*3600}{c_W[J/K,kg]*dT[K]} - Q_{idle}[kg/h]$$

The calculated sap flow rate is in terms of sap flow per whole stem.

*The value "3600" converts the sap flow values from kilograms per second to kilograms per hour (note that "J" = "W.sec"). The following equation considers the preset constant dT (2 K or 4 K) and module conversion factor (-25 + 0.25*mW/K, mV). The value "1000" converts [mW] to [W]. Note that the output signal is in terms of P/dT [mW/K]:*

$$Q[kg/h] = \frac{(-25+0.25*U_{sig}[mV])*3600}{4186.8[J/K,kg]*1000} - Q_{idle}[kg/h]$$

and after calculation

$$Q[kg/h] = -0.0215 + 0.000125*U_{sig}[mV] - Q_{idle}[kg,h]$$

5.4. Data handling – EMS dataloggers

When an EMS datalogger is used for data collecting, the sap flow values calculation is already included in the sensor library. **Please refer also to Mini32 software manual for more information.**

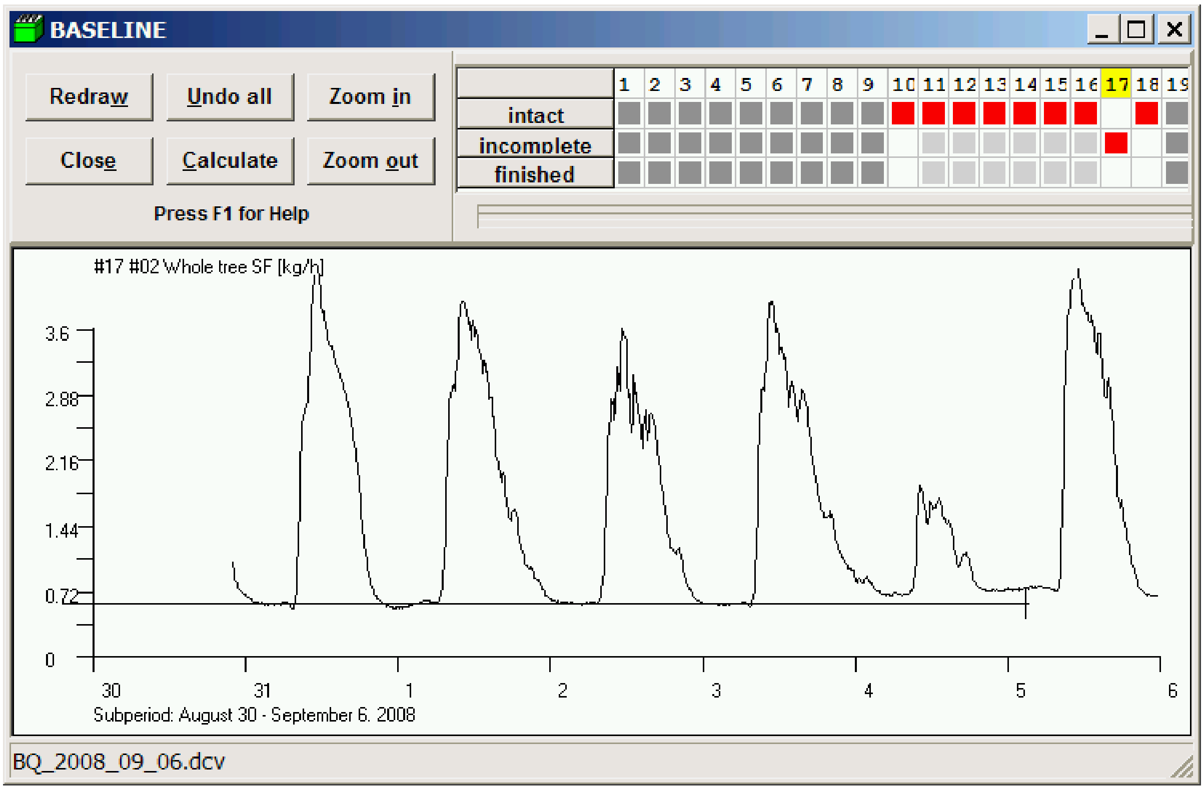
5.4.1. Sap flow values calculation

When the *F098* gauge (Sap flow EMS62) is chosen for the sensor library, the sap flow values in terms of [kg/hr] are calculated from the module output [mV] according to equation (3) automatically during the conversion from downloaded *.hex file to *.dcv file format suitable for next operation.

However, in order to get "net" sap flow data, it is necessary to (manually) subtract the baseline representing the "fictitious flow" due to heat loses from the heated space. See next point.

5.4.2. 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 when the software recognizes a data file coming from a sap flow system. With files coming from some older loggers is necessary to push Alt+F8 keys in graphic setup screen to activate the baseline button.



Note: Colors in upper line indicate channel status from the point of view of sap flow measurement:

- *black – unused channels (no one in following picture)*
- *grey – voltage channels generally suitable for sap flow measurement but when no sap flow gauges from gauge library were selected (a special case when a general polynomial equation has been chosen instead of predefined sap flow gauge)*
- *red - predefined sap flow channel (EMS51, EMS52, THB 4 el; 0.63 etc.)*

Daily courses of sap-flow values from a chosen channel are displayed on the screen. The keyboard arrow keys driven cursor that appears on the beginning of x-axis allows creating a line connecting the points on the curve that shows the situation at 3 a.m. - zero line. This way, the "fictive" sap flow values caused by heat losses from the sensor are subtracted. 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, changes of heat losses as a consequence of changes of sapwood water content etc. Zooming x-axis to longer time interval sometimes helps to see the trend. Principally, just a small and slow change of baseline is expected with properly installed sensors; mostly related to stem growth. Wet foam inside the sensor does not influence the baseline significantly.

5.5. Switching off

Just switch off the switch on the front panel of the module.

5.6. Sensor dismounting

Sequence of dismounting operations:
- Remove the radiation shield
- Disconnect cable connectors
- Open both sensor parts
- Remove both needle sensors from the stem
- Fill a potential stem wounds with a natural wax.

5.7. Maintenance

Principally, the sap flow rate measuring equipment does not need any special maintenance. Remove the resin from foam parts if necessary by light petrol. Do not immerse sensor to any dilution.

6. TOOLS

The only tool sometimes necessary for installation is a drill.

The drill is necessary for drilling holes for sensor needles (0.6 mm diameter) in xyloid stems. It is strongly recommended to use a drill with controlled revolutions according to tissue hardness. The drill should keep revolutions nearly independent to drilling load in order to avoid overheating or burning plant tissues.

A special cordless drill set is offered to this purpose:

It consists of the drill, battery box with electronics and battery charger. The drill keeps low revolutions until it faces a hard xylem. Then, it increases the power until the drilling resistance gets low again. The recommended drill bit diameters ranges between 0.8 to 1.0 millimeters. Proper bits should be chosen according to xylem properties. Principally, the smaller hole the better.

The drill battery should be kept fully charged. Hook it to the charger after each use and also after each three months for a few hours. Few days long recharging does not make anything wrong.

7. 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.

Literature:

Lindroth, A., Cermak, J., Kucera, J., Cienciala, E., and Eckersten, H. 1995. Sap flow by the heat-balance method applied to small-size salix trees in a short-rotation forest. Biomass and Bioenergy 8: 7-15.

Cermak, J., Kucera J., Nadezhdina, N. 2004. Sap flow measurements with some thermodynamic methods, flow integration within trees and scaling up from sample trees to entire forest stands. Trees 18: 529-546