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IMPLEMENTATION ISSUES OF A PC-BASED LABORATORY TEST AND MEASUREMENT EQUIPMENT

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SUMMARY

Experimental research and testing is commonly cost intensive and the traditional instrumentation technologies are often not very flexible. Today's computers and the peripheral hardware are a convenient way to implement more flexible and more complex test and control applications. Within the scope of the new European certificate of approval for metal anchors a variety of laboratory tests have to be performed. One of these tests and its implementation by PC-based technologies is presented in this paper.

Keywords: Experimental Research Facilities, Test and Measurement, Laboratory Instrumentation, Process Control

1. INTRODUCTION

The continually improving price/performance ratio of today's computers makes it convenient for scientists and engineers to use PC-based instrumentation technologies in test and measurement environments. Unlike traditional instrumentation technologies that are often inflexible and cost intensive, computers and appropriate peripheral accessories are a suitable tools for a very broad spectrum of experiments and applications. This starts from simple measurement tasks and ends up with distributed automation and control systems, as can be found for example in industrial manufacturing processes. The most significant advantage of such a system is the speed and the versatility. Computers manage the acquisition of data from multiple sensors with high sampling rates, save the data, manipulate and display the data, and, if required, make use of the results to perform control functions. Additionally, modern computer architectures support good man-machine-interaction and are highly connective and flexible with regard to extensions, while common "black box" – solutions are very often limited in functionality and interactivity. In the following sections we would like to present a PC-based instrumentation and control equipment that was implemented by the author for tests on fasteners that had to be done with respect to the new European certificate of approval (EOTA, 1997). While the approval-guidelines prescribe a lot of different tests, we will exemplarily focus on the crack movement test according to the guideline of approval of metal anchors for use in concrete, table 5.1, line 5. Application specific parameters like anchor geometry, concrete strength, etc. are not relevant for the instrumentation and control technologies and therefore not discussed in this paper.

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2. CRACK MOVEMENT TEST ETAG 5.1/5

The guideline (EOTA, 1997) postulates some general quality parameters for the testing equipment, so all tests for approval have to be carried out using measuring devices with traceable calibration, the measuring error for loads shall not exceed 2 % throughout the whole measuring range, displacements have to be recorded continuously with a measuring error not greater than 0.02 mm. After the installation of the anchors (up to 5 anchors in one crack) the maximum ($N_{max,S}$) and minimum ($N_{min,S}$) loads applied to the test member must be determined such that the crack-width under $N_{max,S}$ is $\Delta w_1 = 0.3$ mm and under $N_{min,S}$ is $\Delta w_2 = 0.1$ mm. To stabilize crack formation, up to 10 load cycles varying between $N_{max,S}$ and $N_{min,S}$ may be applied. Then a tensile load N_p is applied to the anchor after the crack has been opened to $\Delta w_1 = 0.3$ mm. The tensile load N_p shall remain constant throughout the whole test period with an allowed variation of ± 5%. Afterwards the crack has to be opened and closed 1000 times with a frequency of approximately 0.2 Hz, always trying to keep the crack-width Δw_1 nearly constant. For this purpose the loads $N_{max,S}$ and $N_{min,S}$ may have to be varied. Therefore, the crack-width Δw_2 may increase at run time, the crack-width difference, $\Delta w_1 - \Delta w_2$, however, shall always be greater or equal to 0.1 mm. If this condition cannot be fulfilled with $\Delta w_1 = 0.3$ mm, then either $N_{min,S}$ should be reduced or Δw_1 should be increased accordingly. The load/displacement behavior has to be measured up to the load N_p. Afterwards, with N_p kept constant, the displacements of the anchors and the crack-widths Δw_1 and Δw_2 shall be measured either continuously or at least after 1, 2, 5, 10, 20, 50, 100, 200, 500 and 1000 crack movements. After completion of the crack movements the anchor is unloaded, the displacement measured, and a tension test to failure is performed with $\Delta w = 0.3$ mm.

3. TEST EQUIPMENT

The mechanical testing equipment to perform the test described in Chapter 2 encompasses a one-axial mechanical and a three-axial servo-hydraulic aggregate that cope loads from 0 up to 50, 630, and 3000 kN, respectively. The cylinders have displacement ranges of 150, 200, and 300 mm. The control of all axes can be either force driven, displacement driven, or extension driven, allowing parallel interaction of all axes in 3D space. This laboratory infrastructure allows most kinds of mechanical tests, such as tension, compression, shear, strain, fatigue, etc. In order to grant real time behavior with small response times (a few milliseconds), an adaptive controller for all axes is implemented on a transputer board plugged in a personal computer. By the use of a macro-language most generic actions, as e.g., ramps, rectangle, saw-tooth, triangles, etc., can be performed in the load-, displacement-, or strain-domain. Data logging and a very modest user-interaction is possible. This configuration may cope a wide area of applications, however, more sophisticated test arrangements like the crack-width test described in Chapter 2 can not be executed. We could, e.g. imagine that we would like to use up to 5 cracks, each crack-width to be measured on its outer limits, and to average all crack values to get a value for the control loop. This is not possible because of the absence of enough input channels. On the other hand no computational functionality is supported for more complex calculations. For this reason we make use of the systems capability to retrieve external control values through an analog interface.

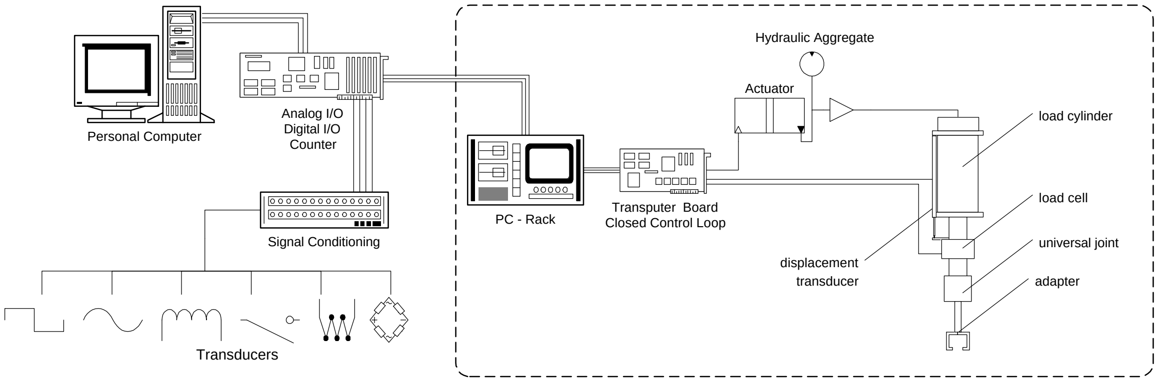


Fig. 1 Instrumentation and Control Architecture (shown for one axis only)

3.1 The Instrumentation and Control System

To communicate with peripheral devices like transducers or actuators we have to realize an interface capable of handling high speed analog and digital communication. In particular, we need to have some signal conditioners, A/D- and D/A-converters, multiplexers etc. There exist a variety of products with different performance and functionality characteristics available on the market. We have chosen a National Instruments™ product, equipped with almost all state of the art features such a data acquisition board should have. This board uses the computers PCI bus and is enhanced with Direct Memory Access and Bus-Mastering capabilities in order to grant high data transfer rates when sampling at high frequencies. This board provides 64 analog inputs with sampling rates up to 100 kS/s and 16-bit resolution, analog and digital triggering, two 24-bit, 20 MHz counter timers, 8 digital I/O lines, and two 16-bit analog outputs. Certain transducer outputs must often be conditioned to provide signals suitable for the data acquisition board. Special signal conditioning accessories amplify low level signals, isolate, filter, and excite transducers to produce high-level signals.

Additionally, most manufacturers deliver very powerful drivers so that we do not have to care about tedious low-level register programming. All functionality is accessible through library calls from any high level programming language as, e.g., C++, Delphi or Visual Basic. As scientists and engineers should not have to be a computer scientists to implement their application, there exist graphical programming environments that offer the flexibility of a powerful language without the associated difficulty and complexity of traditional programming languages. LabVIEW is probably the most powerful representative of these development tools, the graphical programming methodology is almost inherently intuitive to scientists and engineers. While implementing different applications in both LabVIEW and high level languages, the author gained the experience that the choice of the software tool may depend on the complexity of the application. Small applications can be very easily developed and maintained by the use of graphical environments, while bigger and more complex tasks should, if possible, still be implemented by the use of high level languages. An additional criteria for the selection of a suitable development environment is the presence of adequate analysis libraries to perform online, e.g. Fast Fourier Transformations etc. (Weißmann, 1998).

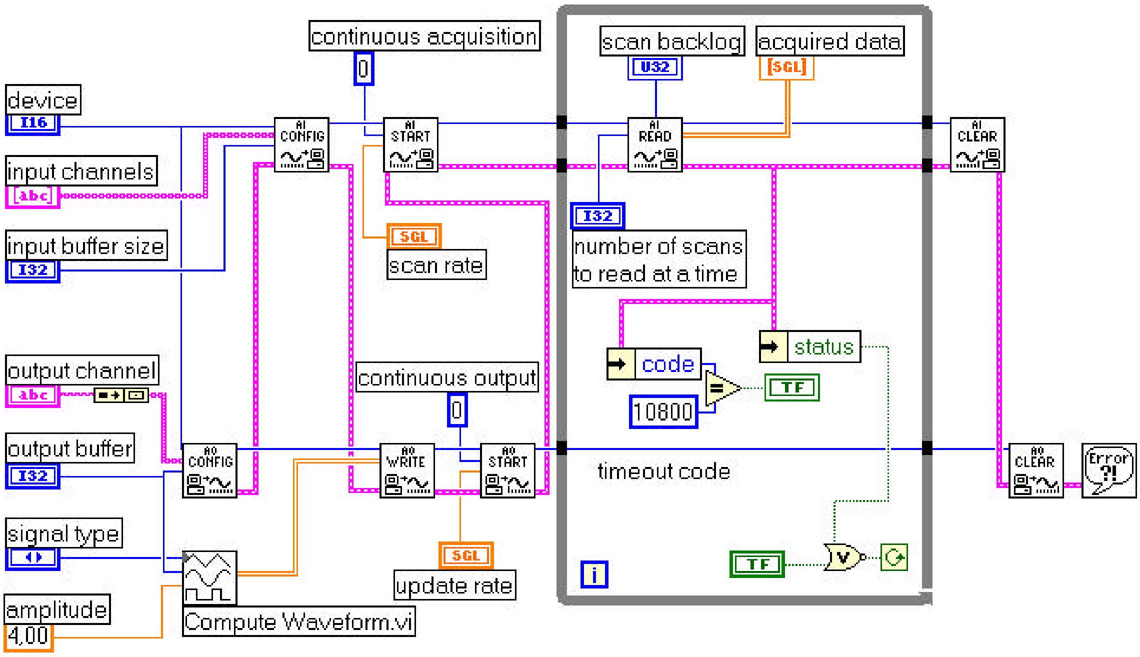


Fig. 2 LabVIEW - block diagram sample for simultaneous buffered Analog I/O

```
Private Sub Start_Click()
    Graph.ClearData
    AI.Device = Device
    AI.Channels.RemoveAll
    AI.Channels.Add Channel, UpperLimit, LowerLimit
    AI.NScans = Val(NumScans.Text)
    AI.ScanClock.Frequency = Val(ScanRate.Text)
    AI.Configure
    AI.Start
End Sub

Private Sub Stop_Click()
    AI.Stop
    AI.Reset
End Sub

Private Sub AI_AcquiredData(Voltages As Variant, BinaryCodes As Variant)
    Graph.PlotY Voltages
    SaveToDisk Voltages, Filename
End Sub
```

Fig. 3 Visual Basic 5.0 sample code for continuous data acquisition

4. TEST ARRANGEMENT

Now we will focus on the test arrangement for the crack movement test as described in section 2. After mounting the concrete slab, a tensile load has to be applied in order to crack the test member. Depending on the size of the anchors and the possibly resulting pullout-cone we have to select one or two cracks where the anchors should be installed. The inductive displacement transducers mounted on both sides of the test member have to be placed at anchorage depth in their zero position. Afterwards they must be reset in order to eliminate an eventual offset when the crack-width is zero. When the anchors are installed, the pneumatic cylinders, used to bring up the tensile load N_p, are connected to the installation adapters of the anchors. To get an almost load-free contact between the pneumatic cylinder and the anchor, a very small pressure of approximately 0.1 bar has to be brought up and the displacement transducers mounted on the cylinders are reset to zero to eliminate this initial vertical displacement. Before the test is started, the crack has to be opened and closed 10 times to stabilize the crack formation, ending with a crack-width of $\Delta w = 0.3$ mm. After selecting the number of cycles, the frequency, and the file to log the measured data, we can bring up the tensile load N_p and start the 1000 sinusoid crack movement cycles. The load and displacement values of the servo-hydraulic cylinder used to open the crack are retrieved through the analog interface as lined out in section 3. All data acquisition and control actions are performed by a program running on an independent personal computer connected to the testing machine. The crack-width is yielded by averaging all mounted displacement transducers, where some consistency checks eliminate transducers with non-plausible values. This is an important issue in the case a transducer is corrupted by some external influences. Upper and lower crack-widths, vertical displacements etc. are stored continuously to a logging file. When the last cycle is done, we unload the anchors by removing the tensile load N_p. When the pneumatic cylinders are removed, a tension test to failure is performed with a crack-width of $\Delta w = 0.3$ mm.

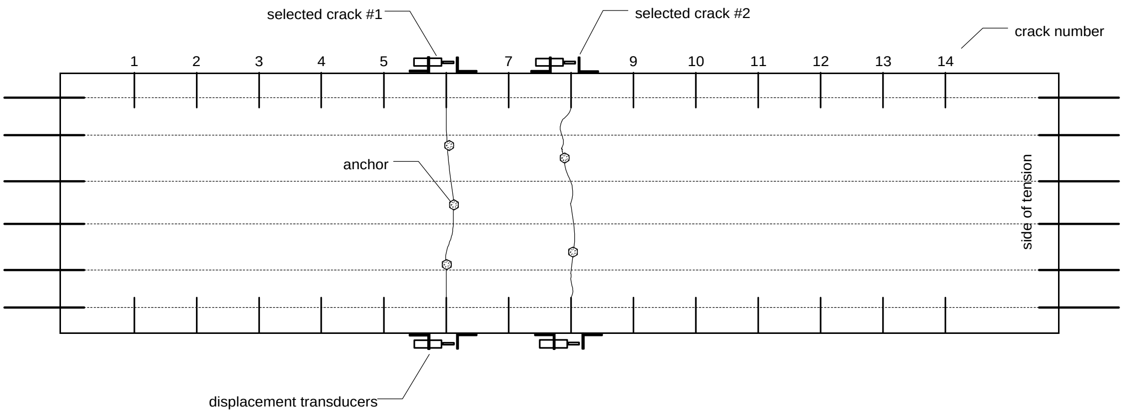


Fig. 4 Test member, anchor arrangement, and displacement transducers

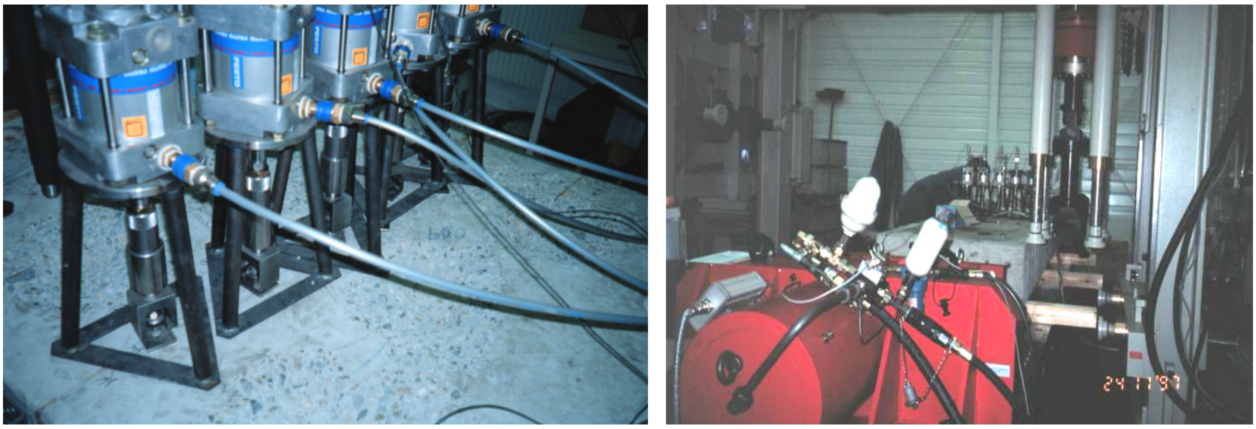
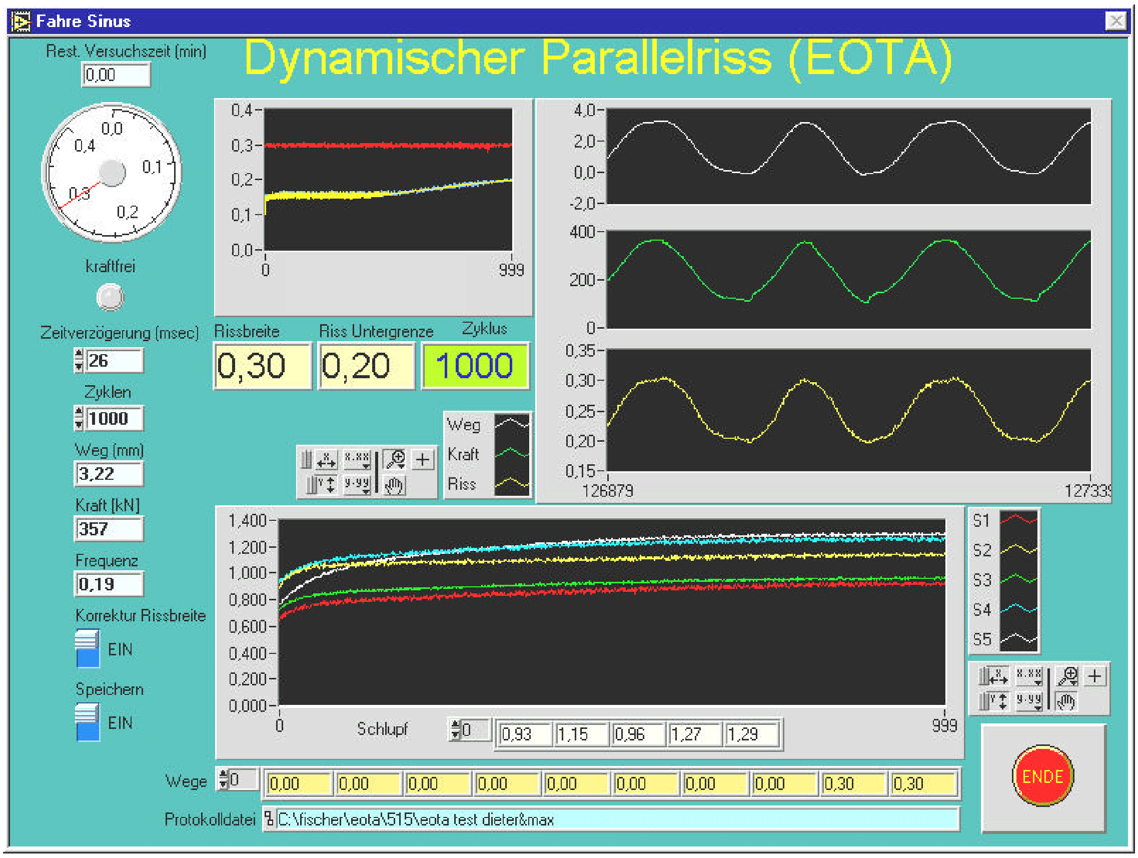


Fig. 5 Pneumatic cylinders to bring up the tensile load and the servo-hydraulic cylinder

5. IMPLEMENTATION ISSUES

As this paper should only give a brief overview of the concepts used to implement a PC-based test and measurement equipment we would not like to get too much lost in detail regarding the programming techniques, used data types etc. For this reason we would like to present a part oft the user interface and a simplified flow-chart diagram of the program that was implemented to compute the crack movement test.



Rest. Versuchszeit (min) 0,00

Zeitverzögerung (msec) 26

Zyklen 1000

Weg (mm) 3,22

Kraft [kN] 357

Frequenz 0,19

Korrektur Rissbreite EIN

Speichern EIN

Rissbreite 0,30

Riss Untergrenze 0,20

Zyklus 1000

Schlupf 0 | 0,93 | 1,15 | 0,96 | 1,27 | 1,29

Wege 0 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,30 | 0,30

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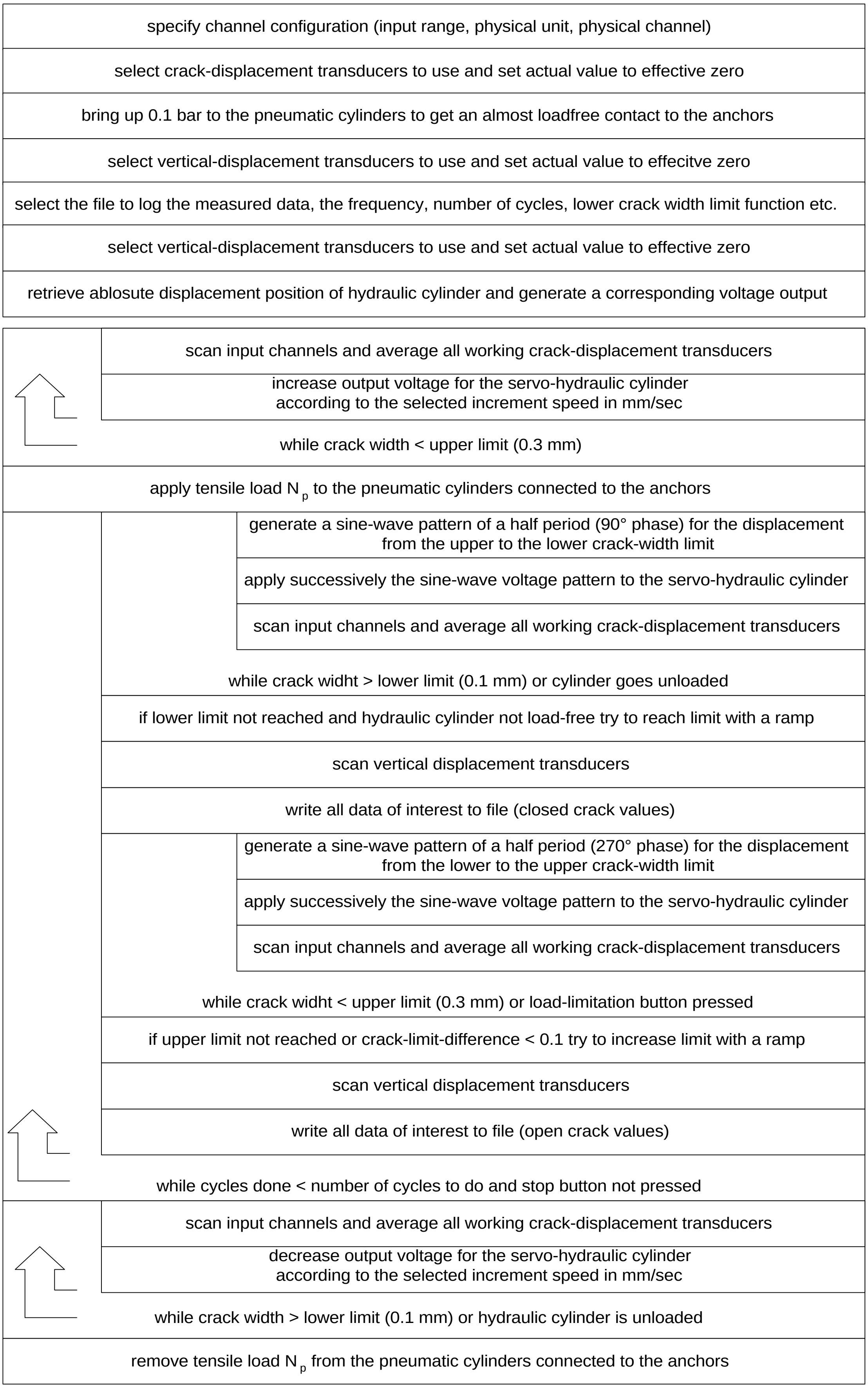
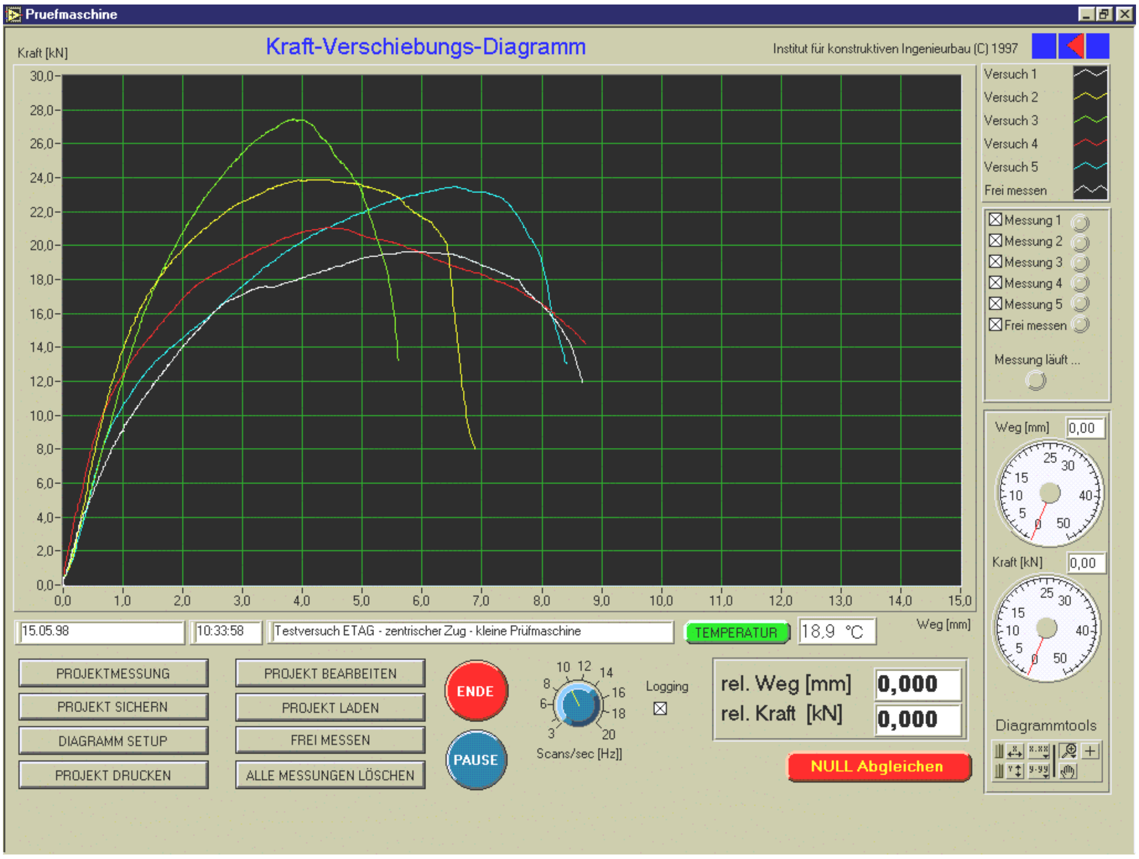
Fig. 6 User interface to perform the crack movement test according to ETAG 5.1/5



```
specify channel configuration (input range, physical unit, physical channel)
select crack-displacement transducers to use and set actual value to effective zero
bring up 0.1 bar to the pneumatic cylinders to get an almost loadfree contact to the anchors
select vertical-displacement transducers to use and set actual value to effecitve zero
select the file to log the measured data, the frequency, number of cycles, lower crack width limit function etc.
select vertical-displacement transducers to use and set actual value to effective zero
retrieve ablosute displacement position of hydraulic cylinder and generate a corresponding voltage output
    scan input channels and average all working crack-displacement transducers
    increase output voltage for the servo-hydraulic cylinder
    according to the selected increment speed in mm/sec
while crack width < upper limit (0.3 mm)
apply tensile load $N_p$ to the pneumatic cylinders connected to the anchors
        generate a sine-wave pattern of a half period (90° phase) for the displacement
        from the upper to the lower crack-width limit
        apply successively the sine-wave voltage pattern to the servo-hydraulic cylinder
        scan input channels and average all working crack-displacement transducers
    while crack widht > lower limit (0.1 mm) or cylinder goes unloaded
    if lower limit not reached and hydraulic cylinder not load-free try to reach limit with a ramp
    scan vertical displacement transducers
    write all data of interest to file (closed crack values)
        generate a sine-wave pattern of a half period (270° phase) for the displacement
        from the lower to the upper crack-width limit
        apply successively the sine-wave voltage pattern to the servo-hydraulic cylinder
        scan input channels and average all working crack-displacement transducers
    while crack widht < upper limit (0.3 mm) or load-limitation button pressed
    if upper limit not reached or crack-limit-difference < 0.1 try to increase limit with a ramp
    scan vertical displacement transducers
    write all data of interest to file (open crack values)
while cycles done < number of cycles to do and stop button not pressed
    scan input channels and average all working crack-displacement transducers
    decrease output voltage for the servo-hydraulic cylinder
    according to the selected increment speed in mm/sec
while crack width > lower limit (0.1 mm) or hydraulic cylinder is unloaded
remove tensile load $N_p$ from the pneumatic cylinders connected to the anchors
```

Fig. 7 Simplified flow-chart diagram for the crack-movement program

The tension test to failure for small anchors is performed by the use of a mechanical one-axial machine. Anchors with failure loads beyond 50 kN have to be executed on a servo-hydraulic aggregate. The following figure shows the user interface with the typical load/displacement diagrams of a set of anchors.



15.05.98

10:33:58

Testversuch ETAG - zentrischer Zug - kleine Prüfmaschine

TEMPERATUR 18,9 °C

Weg [mm] 0,00

Kraft [kN] 0,00

rel. Weg [mm] 0,000

rel. Kraft [kN] 0,000

Fig. 8 User interface to perform the tension test to failure

6. CONCLUSION

The presented combination of hard- and software components enhances engineers and scientists to develop a flexible and professional test and measurement equipment at passably costs. The presented crack movement test is a good representative for a non-standard test composition difficult to realize by a fix-wired black-box solution. With the present work the author has shown by practice the feasibility and benefit of a PC-based instrumentation system. However, the employment of these modern technologies is not suitable only for the use in laboratory environments. Low cost transducers and network technologies allow new applications in the field of long term monitoring and supervision to come into being. Future work will investigate on methods and applications for modern monitoring tasks on existing structures, such as, e.g., load- and crack-measurements on bridges (Bogath, 1997).

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