The X-ray stress measurement method, which takes advantage of the X-ray diffraction phenomenon and is used to obtain stresses in metallic materials, ceramics, and the like polycrystalline aggregates by measuring their lattice distortions, has salient features in that: (1) measurement is non-contact and non-destructive, (2) not only added stress but residual stress is measurable, and so are (3) exceedingly small portions (approx. 1 mm² in min.), (4) stress in a thin layer (1~20 µm), and (5) stress in a particular phase among multi-phase alloy.

Hence, this measurement technique is especially effective in such instances as: (a) measurement of mechanical parts or structures not allowed to be damaged or destroyed, (b) measurement of residual stress or time-flies change other than that of added stress caused by external force to the test body, (c) measurement of local stress distribution in the plane, and (d) measurement of stress in a surface thin layer or that of minute stress distribution in the direction of depth.

It is not seldom that the stress value, an important piece of information in the studies of material strength, plays the leading part in the examination and improvement of heat treatment and working techniques in the manufacturing process, the quality control of products, the inspection of integrity and reliability of mechanical parts and structures, the estimation of their remaining lifetime, and so on. Further, the same is the case with fracture analysis in respect to the cause, process, etc. when unfortunately such an accident occurs. The necessity and effectiveness of the stress measurement are thus markedly high not only in laboratories but in the field as well.

Consequently, it is imperative that X-ray stress analyzers be given functions which permit the measurement of mechanical parts and structures of various shapes and sizes to cope with diverse facilities in the field, besides handling test pieces for laboratorial use. Moreover, practical materials are not necessarily in a state easy to measure from the X-ray crystallographical standpoint. They can have coarse crystal grains or textures. They can be under complex stress conditions. Their kinds also widely vary; iron, copper, aluminum and other metals as well as nonmetallic materials like ceramics. Strainflex series MSF-2M (Fig. 1 -(a)) and PSF-2M (Fig. 1-(b)) are
specifically designed to meet these research and practical requirements at the maximum.

Design emphasis is put on the following points as an approach to a field-oriented equipment.

(a) Parallel beam X-ray optics. This optical system has relieved the measurement from alignment errors making it easy to measure large samples of complicated shapes and actual equipment in the field.

(b) A component system design. The whole system may be divided into each component of goniometer, stand, control/data processing unit, X-ray generator, and heat exchanger. Both the models PSF-2M for field use and MSF-2M for laboratorial use consist of exactly the same components except the stand, and these components are designed to be light in weight and small in size to facilitate transportation and installation (unit weight: 10-25kg). The stand is also light and compact, and is available in two types for field use (PSF-2M) and for laboratorial use (MSF-2M), the latter equipped with many functions for postural adjustment.

(c) A built-in microprocessor. Simplicity of operations is enabled, as the microcomputer automatically handles all of the complicated, troublesome procedures such as equipment control, determination of the optimum measurement conditions, computation of the measurement result, and so on. Upon the completion of setting, all that is necessary for the operator is to press the buttons for "X-ray ON", "material selection", "incident angle setting", and "START" in sequence, so that even an inexperienced operator can readily conduct the operation.

Figure 2 shows an example of output data. The measurement conditions first come out, followed by the output of the peak position of a diffraction profile, FWHM, peak intensity, integrated intensity, and integral breadth regarding each angle of incidence. Lastly, the stress value and its reliability are printed out. The operator may just sit and wait for the final result. It is also possible to get a printout of raw profile data when so desired.

(d) Fixed $\psi$ method. Employment of this method has substantially lifted the existing restrictions on the shape, material and other crystallographical factors with respect to the object for measurement, an impor-

Fig. 2. Print-out Format

Fig. 3. Comparison of Methods. (a) Fixed $\psi_0$ method (b) Fixed $\psi$ method ($\theta$-20 or $\psi$-20 linking method)
tant breakthrough for operation in both the laboratory and the field. Since it is often the case that X-ray stress analyzers deal with large samples and structures, the measurement of diffraction profiles are invariably conducted with the sample kept in a stationary position. In this instance, in order to avoid a complex mechanism, conventional X-ray stress analyzers have been customarily designed to have the X-ray detector revolve alone in the measurement of diffraction profiles, i.e. the so-called fixed $\psi_0$ method (Fig. 3-(a)) is employed. A drawback of this method is that in the case of handling samples having a texture, such as worked plastic materials, casting, welds, etc., or samples having coarse grains where the probability of presence in terms of the orientation of crystal grains is not isotropic, the resulting measurement accuracy is exceedingly low, thus greatly narrowing the applicable range for practical materials. To resolve this problem the Rigaku X-ray stress analyzer is designed to incorporate the fixed $\psi$ method ($\theta$-2$\theta$ or $\psi$-2$\theta$ linking method) in which case scanning is made, with the sample fixed, to measure diffraction profiles by interlocked operation of the X-ray detector and the X-ray tube.

Currently, moreover, theoretical studies are being made actively concerning the $\psi$ split phenomenon in the case of a multi-axis stress condition or a sample having a texture as well as regarding the problem of nonlinearity in 2$\theta$-sin$^2\psi$ diagram. The fixed $\psi$ method is indispensable for these types of studies.

(c) Oscillation method. Adopted is the stepwise oscillation method with respect to the angle of X-ray incidence, where the oscillation cycle and the fixed time (F.T.) mode operation are synchronized. As a...
result the stress analysis measurement accuracy of coarse-grain samples has been remarkably enhanced. The oscillation width is selectable in three steps; ±3°, ±5°, and ±7°. So far as samples to the extent of 100 µm or so in the grain size are concerned, the joint use of the +3° oscillation and the fixed ψ method is sufficient to measure them with a high degree of accuracy (Fig. 4).

The aforementioned approach has realized stress measurements of actual equipment and structures in the field at the same level of accuracy as in laboratories without degrading the data quality.

The following options are available to upgrade the Strainflex according to the purpose of use.
(1) A ten-key system which permits optional setting of the measurement conditions externally.
(2) A build-up system for connection to a host computer to enable the measurement sequence, data processing and output to the plotter as desired.
(3) A ratemeter system to allow real-time monitoring of diffraction profiles.
(4) An electrolytic polisher designed to polish the sample without causing stress. A metallographic inspection unit consisting of the same polisher, a minigrinder and supplies for metallographic observation.
(5) A back reflection camera for checking the crystal grain size and for observing texture.
(6) An attachment for quantitative measurement of retained austenite which delicately affects the strength of materials.

Measurement Example of a Fillet Welded Joint

The Strainflex was used to measure surface residual stresses in the direction at right angles to the bead of a fillet welded joint. The sample is high tensile steel of 60 kg class. The measurement result is shown in Fig. 5. Prior to the measurement, electrolytic polishing was conducted against hot oxidized steel in the surface to remove it to the depth of about 60 µm without causing stress. The time required for measurement was about 10 minutes per point.