THICK-WALLED ALUMINUM PLATE INSPECTION USING REMOTE FIELD EDDY CURRENT TECHNIQUES

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INTRODUCTION

The detection of defects that are located deep in thick walled (>12 mm) aluminum plates is of interest to both the aircraft and space industries. Conventional eddy current (EC) techniques are limited to the inspection of surface and subsurface anomalies. Newly developed high sensitivity magnetic sensors, such as magnetoresistive elements and superconducting quantum interface devices (SQUIDs) have enhanced the EC technique's capability. Such sensors can be used to detect flaws that are located deep in aluminum plates. However, inspection of a defect located 12 mm to 25 mm below the surface of an aluminum plate is beyond the ability of conventional single frequency EC techniques.

The remote field eddy current (RFEC) technique, that is currently being used for metallic tubular product inspection, is characterized by equal sensitivity to a flaw irrespective of its location in the tube wall. In recent few years, it has been successfully extended to the inspection of metallic plates[1], [2]. A prototype of such a probe designed for inspecting thick aluminum plate has been designed and evaluated using finite element models. Preliminary experimental results obtained support the validity of the approach.

This paper presents some of the finite element (FE) modeling and experimental results obtained to date. The experimental results were obtained during efforts to inspect a 12.7 mm thick aluminum plate with a defect machined on the other side of the plate (related to the probe).

PROBE DESIGN

The key objective in designing the RFEC probe is to ensure that the energy flows through the plate wall twice.

In the case of tubes, the eddy current induced inside the tube wall restricts the flux pattern from expanding axially resulting in rapid attenuation of the directly coupled field. In the case of metal plates the following four steps have been taken to force the energy to traverse the plate twice [2]:

1. Using a special designed magnetic circuit consisting of a pot-core and an excitation coil.
2. Employing a magnetic circuit to improve the sensitivity of the pick-up coil.
3. Using an auxiliary coil to help guide the signal path.
4. Excitation and pick-up coils are shielded to minimize direct coupling between them.

It has been shown by both through FE modeling studies and experimental measurements that in the case of an RFEC probe for aluminum plate inspection the auxiliary coil is not necessary, because of the low permeability value of aluminum typical better surface conditions. Consequently, the size of the probe can be reduced significantly relative to probe for inspecting steel plate.

A schematic of the probe is given in Fig. 1. The probe consists of an excitation coil wounded inside a pot-core that provides a magnetic circuit for the flux. The parameters of both the magnetic circuit and the metallic cover are chosen carefully to enable the electromagnetic energy released from the coils to penetrate downward into the plate. The pick-up coil senses the electromagnetic field that traverses the plate from the bottom to the upper surface. The magnitude and phase of the signal are sensitive to the condition (the thickness, permeability and conductivity) of the aluminum plate.

With the help of a FE model, a prototype has been designed and built for inspecting aluminum plates up to 25 mm of thickness. The excitation unit is about 100 mm in diameter and 65 mm in height. Two sensor units, one is with an E-shaped ferrite core the other with a U-shaped core, similar to those used for inspecting steel plate, are used.

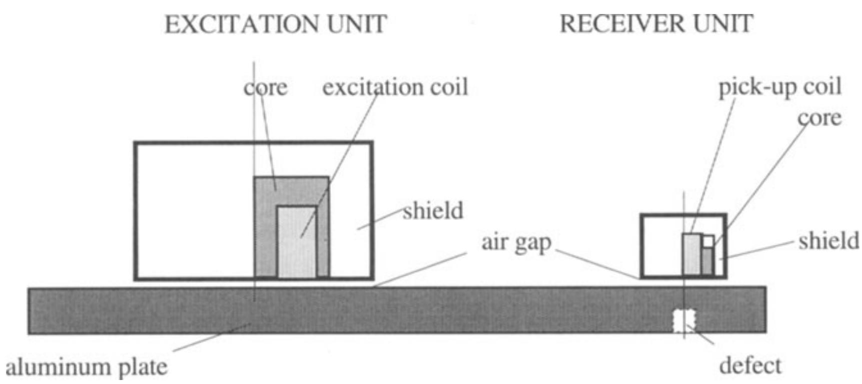

Fig. 1 Schematic of the probe prototype for thick walled aluminum plate inspection.

NUMERICAL MODEL

A linear, 2-D (axisymmetric) finite element code was used to estimate the optimal design parameters of the probe. A simple 2-D code, capable of providing reasonably good estimates quickly, was used to arrive at the initial design of the probe. The performance of the probe was evaluated after the probe parameters were established. Figs. 2, 3 show the magnetic field distributions, equi - *ln*[1](flux magnitude) lines and equi-phase lines, around the probe inspecting a 25 mm thick aluminum plate. Fig. 2 shows a case without any defect, while Fig. 3 shows results obtained with a 20 mm wide, 40% deep slot on the plate on the far side. The lift-off for both cases was 2 mm.

A cursory review of the data reveals little difference between the two plots in the near field (R<60 mm) region. However, if one carefully compares the two plots at the remote field region underneath the receiver unit (130 mm<R>170 mm), a noticeable difference between the two cases can be observed. The difference becomes even more evident in Fig. 4 where the phase distributions on the upper surface of the plate are compared. The phase in the 'defect' case leads the phase values observed in the 'no-defect' case in the remote field region. Note that there is a small area around R=160 mm where the phase is lagging in the case when the defect is present. The lag is due to the special shape of the core of the pick-up coil.

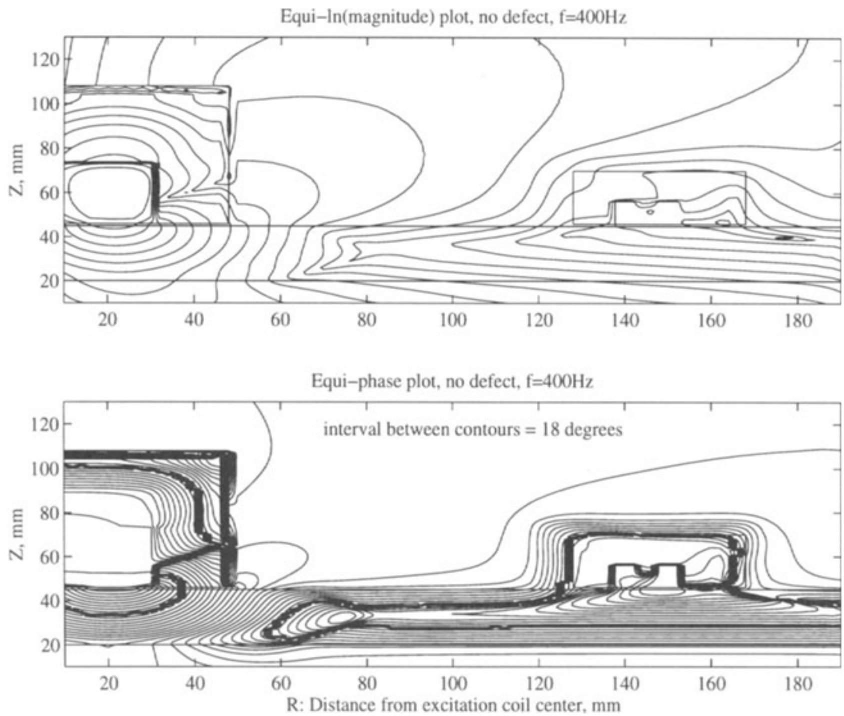

Fig. 2 Magnetic field distribution around the probe used for inspecting a 25 mm thick aluminum plate without defect.

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[1] Natural logarithm.

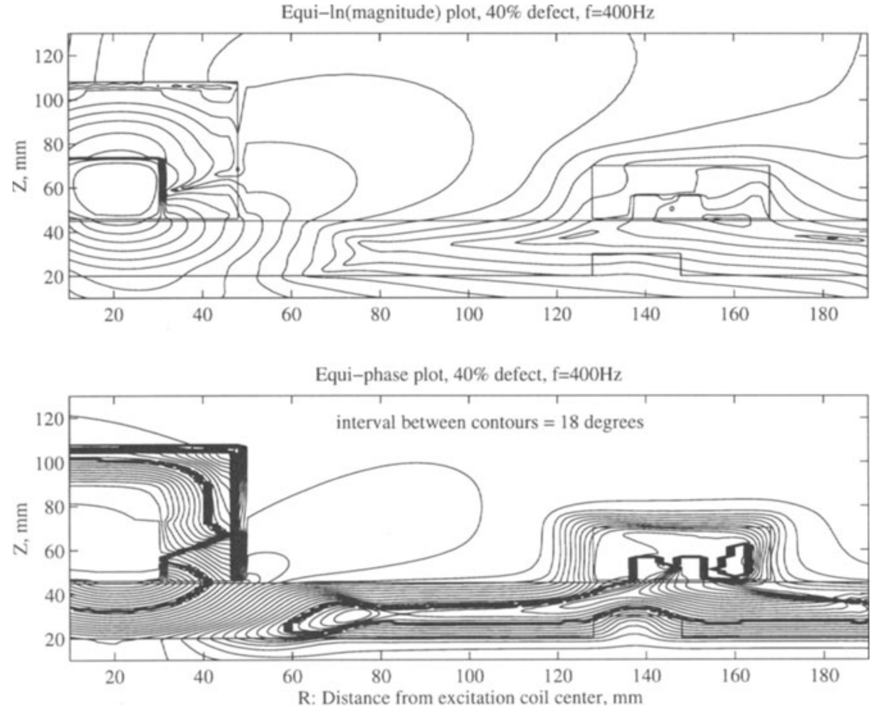

Fig. 3 Magnetic field distribution around the probe used for inspecting a 25 mm thick aluminum plate containing a 20 mm wide, 40% deep defect.

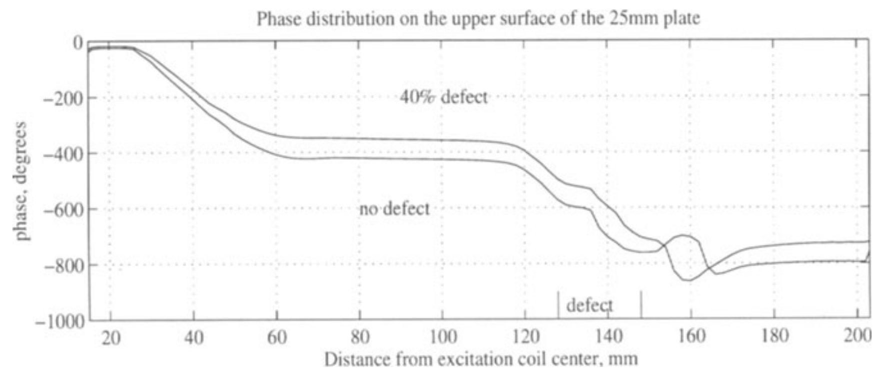

Fig. 4 Comparison of flux-phase distributions right at the upper surface of the plate for the 'no-defect' and the 40% deep 'defect' cases.

In theory, it should not be possible to obtain any signal response to a defect if an axisymmetric FE code is used, since the distance between the probe and the defect is fixed. Neither the probe, located along the R axis, nor the defect, which is a circular slot, vary in location. A 3-D code is required to simulate the geometry accurately. However, for an initial probe design the reduction of computation time represents a higher priority over accuracy, Consequently following approximation was used in arriving at the solution.

If we assume that the scan length ΔR is much smaller than the average radius of the defect, R_{def}, we can ignore the change in defect radius with the radial distance. The assumption allows movement of a defect within ΔR and enables the estimation of the probe responses.

The responses to two defects in a 15 mm thick aluminum plate are shown on Fig 5. The scanning was performed directly underneath the receiver unit (130 mm < R > 170 mm). Their signal phase to *ln*(signal magnitude) trajectories are compared in Fig 6.

EXPERIMENTAL MEASUREMENTS

A 2 mm wide, 25 mm long and 50% deep slot was machined on the bottom side of a 12.7 mm thick aluminum plate. The probe excitation unit and receiver unit are mechanically coupled, with a 25 mm gap in between. Note, the probe is scanned along the length of the defect, while the defects in the FE simulation were perpendicular to the scan direction. An 200 Hz, 0.5 Ampere AC current was applied to the excitation coil. A lock-in amplifier, Model ITHACO 3981A, was used for measuring the signal magnitude and phase. Fig. 7 shows the results when an E-shaped core is used in the receiver unit. Fig. 8. shows the results when a U-shaped core is used.

The phase to ln(magnitude) trajectories of the signals obtained using E-shaped and U-shaped cores are compared in Fig. 9.

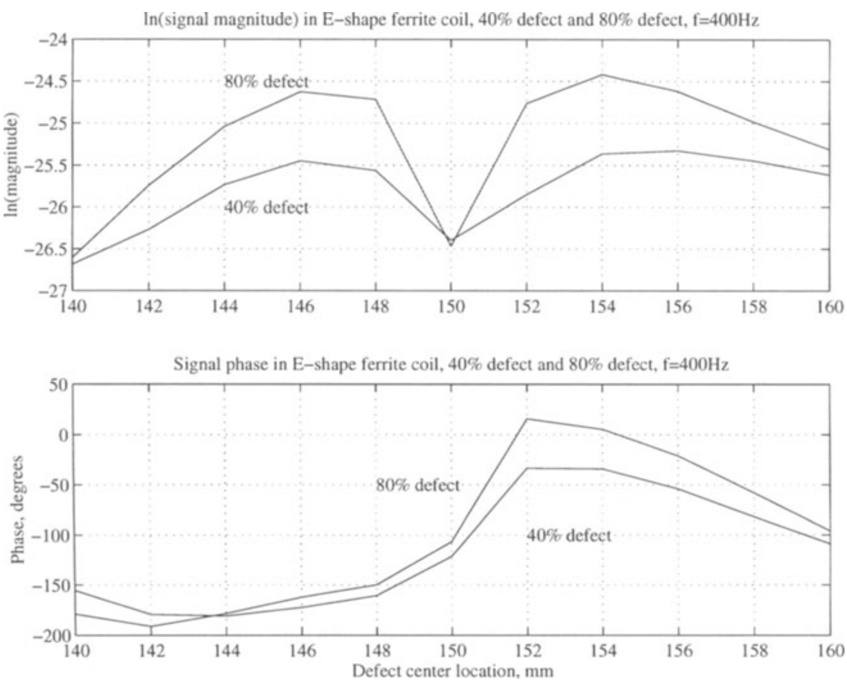

Fig. 5 Simulated signal responses of the probe inspecting a 15 mm thick plate to 40% and 80% deep defects.

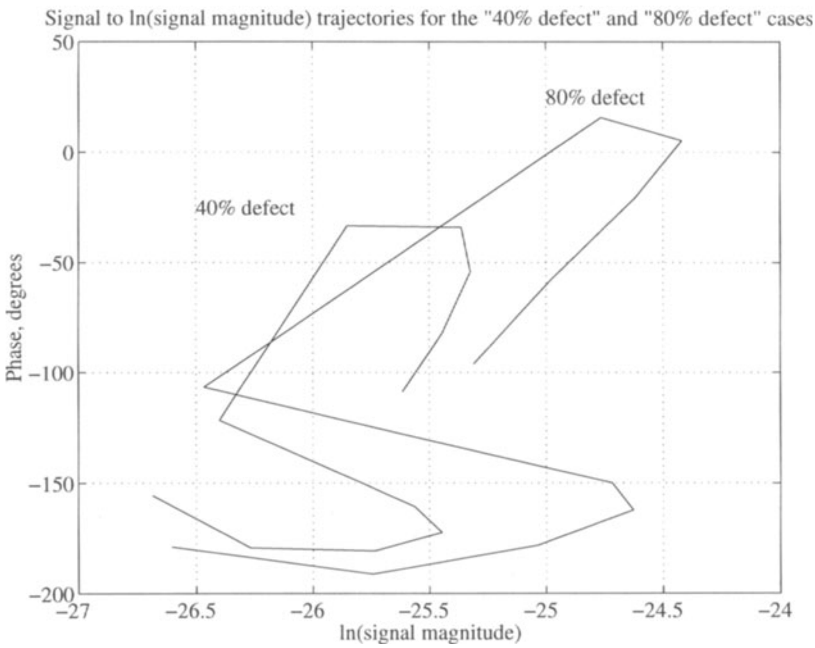

Fig. 6 Comparison of signal phase vs. *ln*(signal magnitude) trajectories for the '40% defect' and '80% defect' cases.

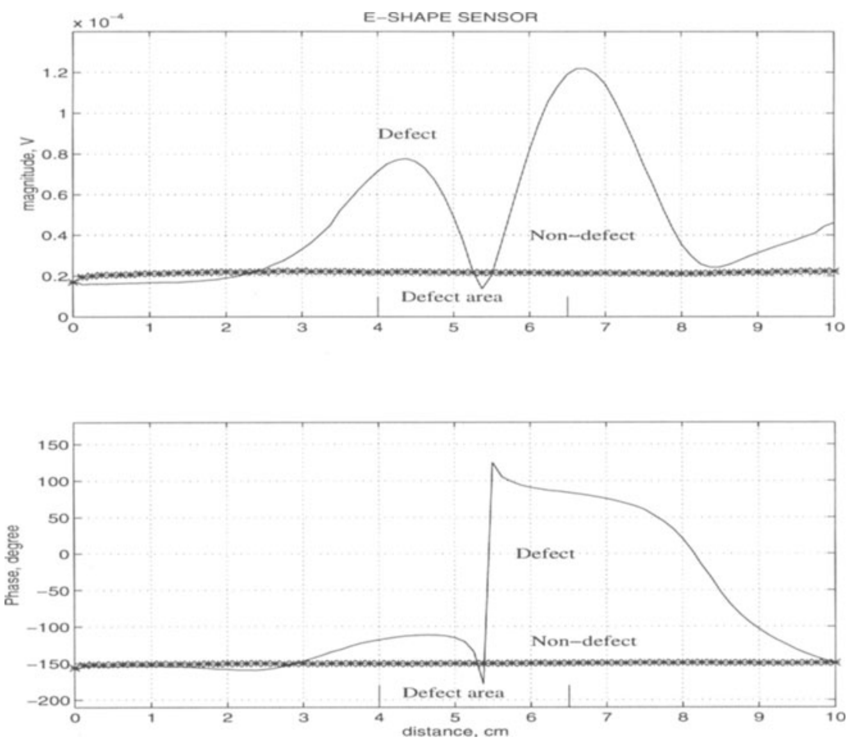

Fig. 7 Signal obtained by scanning the specimen with a receiver using an E-shaped core.

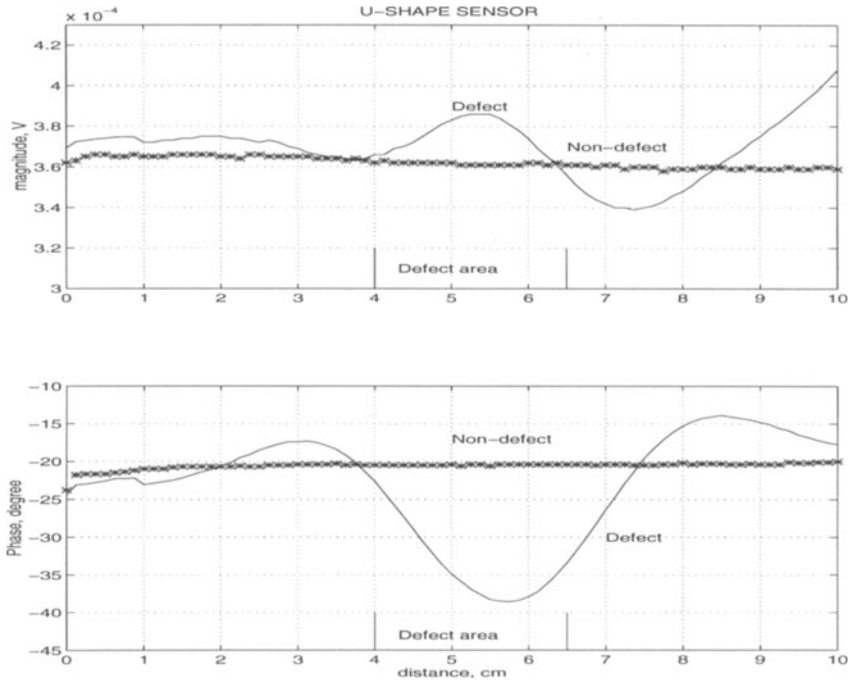

Fig. 8 Signal obtained by scanning the specimen with a receiver using a U-shaped core.

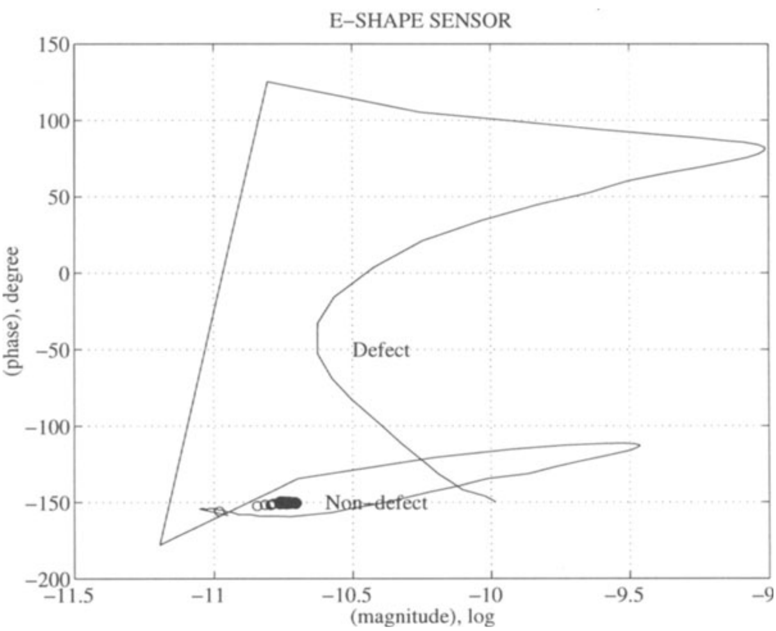

Fig. 9 Comparison of phase vs. *ln*(magnitude) trajectories from signals obtained from a receiver using an E-shaped core. Signals obtained when the probe scans over the defect.

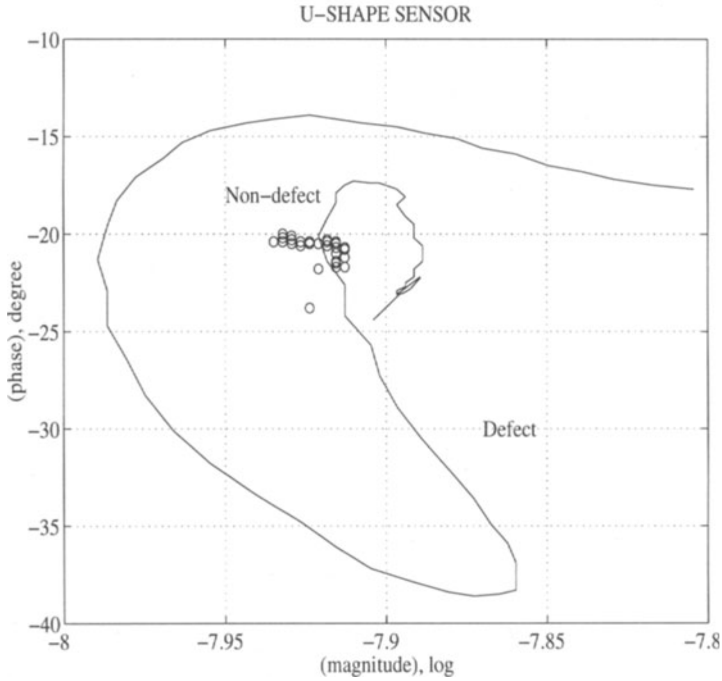

Fig. 10 Comparison of phase vs. *ln*(magnitude) trajectories from signals obtained from a receiver using a U-shaped core. Signals obtained when the probe scans over the defect.

CONCLUSIONS

A novel RFEC probe has been designed and built for inspecting thick aluminum plate employing a finite element model. Modeling results obtained to date show that it can be used for inspecting a plate with thicknesses up to 25 mm. Preliminary experimental measurements carried out on a 12.7 mm aluminum plate demonstrated excellent performance.

REFERENCES

1. Y. S. Sun, S. Udpa, William Lord, and D. Cooley, "A Remote Field Eddy Current NDT Probe for Inspection of Metallic Plates", *Materials Evaluation,* Vol. 54, No. 4, April 1996, pp. 510-512.

2. Y. S. Sun, S. Udpa, William Lord, and D. Cooley, "Inspection of Metallic Plates Using A Novel Remote Field Eddy Current NDT Probe", *Review of Progress in Quantitative Nondestructive Evaluation,* Vol. 15A, Edited by Donald O. Thompson and Dale E. Chimenti, Plenum, 1996, pp. 1137-1141.