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## Infinitesimal Hilbert 16th Problem

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Hilbert 16th Problem (Second Part) is the following:

Given

$$\frac{dy}{dx} = \frac{P(x, y)}{Q(x, y)}, \tag{1}$$

where  $P$  and  $Q$  are real polynomials of  $x$  and  $y$ , what may be said about the number of limit cycles and their relative positions.

Infinitesimal Hilbert 16th problem is one of the restricted version of Hilbert 16th problem, it was posted by V. I. Arnold in 1977 [1] as follows:

Given

$$H(x, y) = h, \quad \omega = Q_n dx - P_n dy,$$

where  $H$ ,  $P_n$  and  $Q_n$  are real polynomials of  $x$  and  $y$ ,

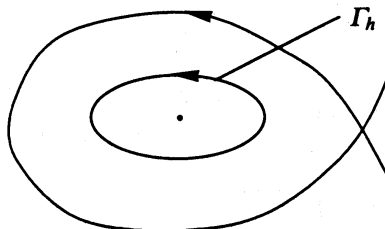


Fig. 1

$\max(\deg P_n, \deg Q_n) = n, \deg H = m + 1$ . Then

$$\Gamma_h \subset (H = h),$$

$$I(h) = \int_{\Gamma_n} \omega.$$

Problem: What is the number of isolated zeros of  $I(h)$  ?

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This problem is closely related to the problem of estimating the number of limit cycles of the following Hamiltonian System with small perturbations:

$$\begin{aligned} \frac{dx}{dt} &= \frac{\partial H}{\partial y} + \varepsilon P_n, \\ \frac{dy}{dt} &= -\frac{\partial H}{\partial x} + \varepsilon Q_n, \end{aligned} \quad (2)$$

where  $0 < |\varepsilon| \ll 1$ .

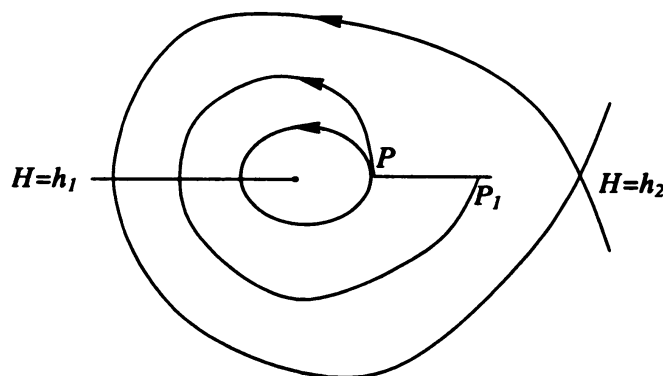


Fig. 2

Then we have

$$\begin{aligned} \Delta H &= \int_0^{T(P, \varepsilon)} \left. \frac{dH}{dt} \right|_{(2)} dt \\ &= \varepsilon \int_0^{T(P, \varepsilon)} \left( \frac{\partial H}{\partial x} P_n + \frac{\partial H}{\partial y} Q_n \right) dt \\ &= \varepsilon \int_{\Gamma_h} (Q_n dx - P_n dy) + O(\varepsilon^2) \\ &= \varepsilon I(h) + O(\varepsilon^2), \quad h_1 < h < h_2, \end{aligned}$$

where  $T(P, \varepsilon)$  is the time along  $\widehat{PP_1}$ . Hence, there exists a periodic orbit of (2) passing through  $P \in \Gamma_h$  if and only if  $\Delta H(h) = 0$ , i.e.  $I(h)$  is the first approximation of the Poincarè return map  $\Delta H$  with respect to “ $\varepsilon$ ”.

Relationship:

- (i) If  $I(h) = 0, I'(h) \neq 0 \implies \exists \text{ hyp. limit cycle } L_{h(\varepsilon)} \rightarrow \Gamma_h \ (\varepsilon \rightarrow 0)$ ; conversely, if  $\exists \text{ hyp. limit cycle } L_{h(\varepsilon)} \rightarrow \Gamma_h \ (\varepsilon \rightarrow 0) \implies I(h) = 0$ .
- (ii) If  $I(h) = I'(h) = \dots = I^{(k-1)}(h) = 0, I^{(k)}(h) \neq 0 \implies$  there are at most  $k$  limit cycles bifurcated from  $L_h$ .
- (iii)  $\#\{\text{limit cycle } s.t. \ L_{h(\varepsilon)} \rightarrow \Gamma_h \ (\varepsilon \rightarrow 0)\} \leq \#\{I(h) = 0\} = Z(m, n)$ .

Here multiplicity taking into account.

In this talk it will be introduced the main results and main methods of how to estimate the number of isolated zeros of  $I(h)$ .

The main methods are as follows:

1. Argument principle [2], [3];
2. Generalized Rolle Theorem [4], [5];
3. Estimate zeros of analytic functions [6], [7].

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